DECEMBER / JANUARY 2025

Aerospace TESTING INTERNATIONAL

Inside this issue

// **HYDROGEN FUEL**
A new research hub aims to change the course of aviation towards zero emissions flight

// **DIGITAL TWINS**
Engineers are leveraging models, data and AI to accelerate aerospace development programs

// **AUTONOMOUS SYSTEMS**
Farms are becoming a fruitful proving ground for the testing of unmanned drones

Proving the Pearl

Rolls-Royce reveals how its Boeing 747 was modified to test the Pearl 10X business jet engine

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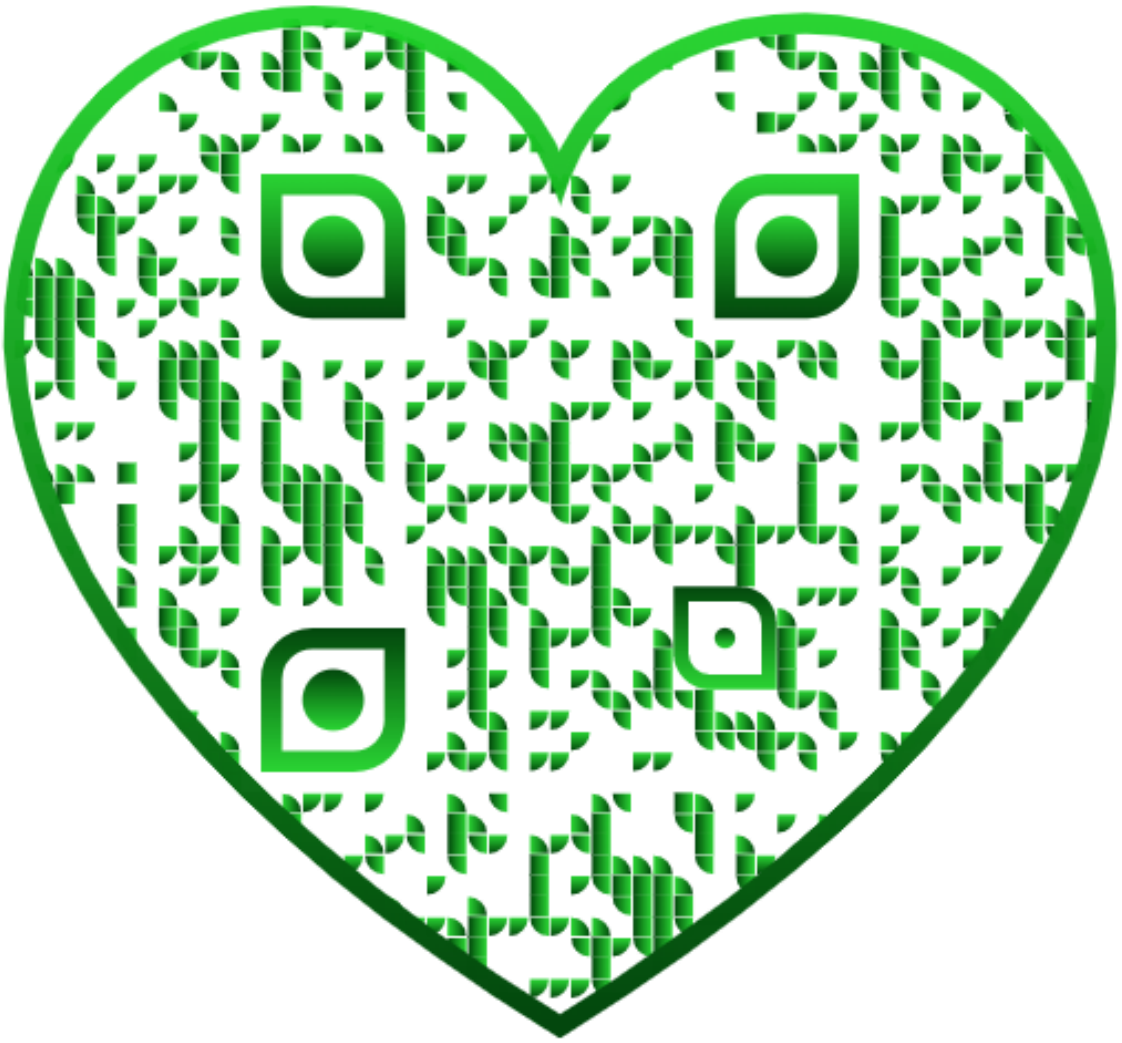

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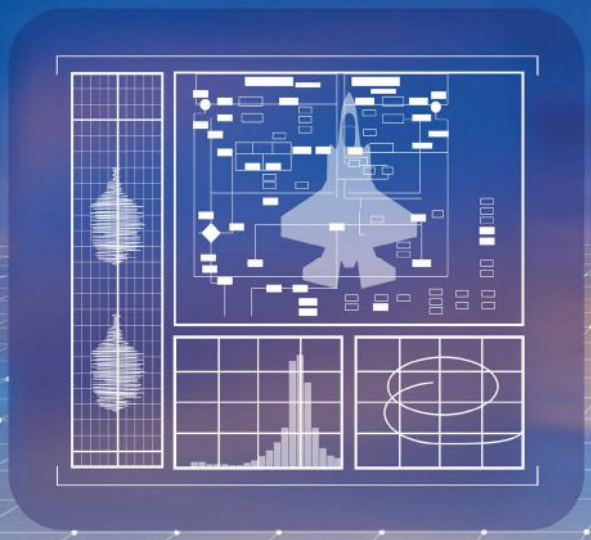

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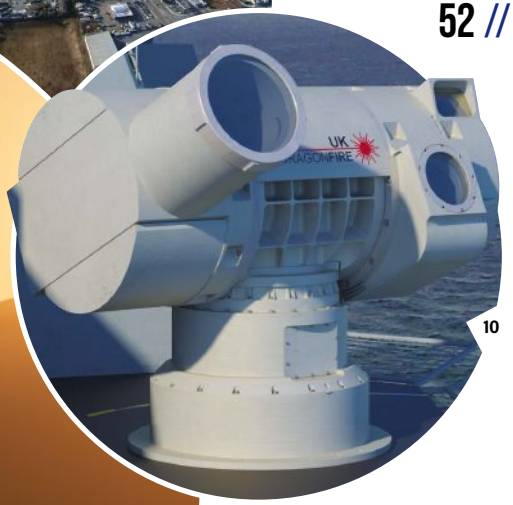
14
30

38
44

52



10

Regulars

06 // WORLD TEST UPDATE
The latest testing news from around the globe

09 // ACADEMIC INSIGHT
R&D that uses NDT for parachute improvements

60 // PRODUCTS AND SERVICES
All the latest product innovations, case studies, company news and more

66 // AFT CABIN
How the X-48 boosted the blended wing body concept

Inside this issue

10 // *Testing Talk: Mike Mew, MBDA*
The director responsible for the UK's DragonFire directed energy weapon program details its progress through testing

14 // *Pearl performance*
How Rolls-Royce measured the capabilities of its latest business jet engine using its Spirit of Excellence 747 flying testbed

22 // *Twinned benefits*
Engineers are examining how to extend the usefulness of digital twins throughout an aircraft's lifetime

30 // *Hydrogen hub*
A multimillion investment is reshaping research facilities at Cranfield University towards aviation's zero-emission future

38 // *Spare parts in space*
The first 3D printers are being tested in orbit to assess their capabilities for producing spacecraft components

44 // *Cameras for confidence*
Computer vision systems in aircraft detect-and-avoid avionics are using technology from existing cameras

52 // *Farming flights*
How engineers are testing autonomous drones for crop spraying and pioneering beyond visual line of sight operations

// Heading into 2025

As we enter 2025 aerospace companies will continue to build the foundational technologies and concepts that will define the aviation and defense industries for decades. The next year should also bring several milestones in areas such as eVTOL aircraft, unmanned drone technology and propulsion electrification.

Increased geopolitical tensions are driving investment in the aerospace and defense programs delivering many of these foundational technologies.

In the USA, the outgoing Biden administration has requested a budget of US$850 billion for the Department of Defense (DoD) in 2025. The EU's 2025 defense budget is almost US$210 billion and Russia is boosting its military spending by 30% to US$145 billion next year.

The result is progress. For example, US advanced air mobility companies that are recipients of US Government funding such as Beta Technologies and Joby look likely to be the first to market with eVTOL aircraft, perhaps during the coming year.

Meanwhile, there is also investment happening on the civilian side. Analysts agree that the air travel sector has fully recovered from the Covid-19 pandemic. According to the International Air Transport Association, demand for global air passenger traffic is expected to grow by 11.6% in 2024 compared with 2023. Global air passenger traffic was up 11.9% year-to-date in August 2024. More growth is expected during 2025.

Underlying this increase in air travel is legislation and societal pressure to reduce emissions in way that helps combat climate change. This is driving future commercial aircraft development programs towards innovations in electrification and alternative fuels for propulsion.

The trickle-down effect for test engineers is more investment, as well as pressure to produce safe and effective products to demanding time scales. Innovation is needed here too, so program goals can be met. 2025 is therefore also likely to be a year where new processes and testing technologies that leverage AI, machine learning and digital twin technologies come to the fore.

Ben Sampson,
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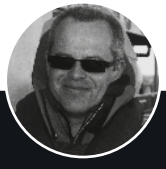

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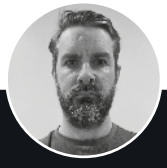

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WORLD *test update*

// NASA FIRES UP X-59 SUPERSONIC ENGINE

NASA has started testing the X-59 Quiet SuperSonic Technology demonstrator aircraft's engine, firing it up for the first time at the end of October.

The Quiet SuperSonic Technology (Quesst) program started in 2016 to develop and validate new ways to minimize the noise made by aircraft when breaking the sound barrier. Engineers believe that a combination of aerodynamic features in its design will turn the characteristic supersonic boom into a thud that is more acceptable to people on the ground.

Data gathered from Quesst about how people perceive the supersonic thumps will be used by regulators to devise new rules for commercial supersonic flight over land. This will enable supersonic aircraft, such as the one that is being developed by Boom to operate at speeds faster than sound overland instead of just over seas.

READ MORE ONLINE

Palmdale, California

// ELECTRA REVEALS FINAL AIRCRAFT DESIGN

Virginia, USA-based Electra has revealed the design of the nine passenger, ultra short take-off and landing hybrid-electric aircraft, it is developing.

Electra has recently concluded a year of flight testing its EL2 Goldfinch two-seat prototype to validate its technology and is now starting the EL9's development phase. The first test flights of the EL9 are planned for 2027, with certification and service entry planned for 2029 under FAA Part 23 regulations.

WATCH THE VIDEO ONLINE

Electra's aircraft take advantage of an aerodynamic concept called blown lift to enable take-offs and landings in distances of less than 150ft (45m).

The blown-lift concept uses propellers on the leading edge and large flaps at the rear of the wing to blow more incoming air downwards. This enables the aircraft to lift off the ground at slower speeds and use shorter runways. According to Electra, the EL9's short take-off and landing capability creates new opportunities to locate air services in urban areas.

Virginia, USA

// HYDROGEN-FUELED TURBOPROP TESTED

Pratt & Whitney is to test a turboprop engine fueled by hydrogen combustion as part of a Canadian Government-funed research program.

Pratt & Whitney will use its PW127XT regional turboprop engine for the first phase of the Hydrogen Advanced Design Engine Study (HyADES) project. The phase will include hydrogen fuel testing of fuel nozzles and combustor rigs, while future phases will target full engine ground testing.

The PW127XT, which launched in 2021 is the latest member of the company's PW100 engine series. According to Pratt & Whitney, the PW127XT engine offers over 3% better fuel efficiency, 40% improved time on wing, and 20% reduced maintenance costs.

Edward Hoskin, vice president of engineering at Pratt & Whitney Canada said, "This collaborative project with INSAT enables us to develop key technologies for future hydrogen powered aircraft."

Quebec, Canada

// EVE TO BUILD EVTOL FACTORY IN BRAZIL

Eve is to build the first factory for its eVTOL aircraft in São Paulo, Brazil. The Embraer company has secured a US$88 million loan from Brazil's National Development Bank (BNDES) to fund the production facility in Taubaté, in the state of São Paulo.

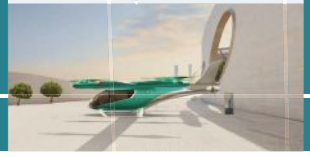
The total expected output of the factory will ramp up to 480 aircraft per year, with the site's production capacity expanded at a rate of 120 aircraft per year.

According to Eve it has the largest number of letters of intent (LOI) to buy eVTOLs with 2,900 LOIs for its eVTOL from 30 customers worth US$14.5 billion in revenue.

The first full-scale prototype of Eve's eVTOL aircraft was revealed in July this year. The aircraft has eight propellers for vertical flight and fixed wings for cruise, with no change in the position of these components during flight.

The concept also features an electrically powered pusher for redundancy and to ensure high performance levels, safety, dispatch reliability, and low operation costs.

São Paulo, Brazil



// STARTUP REVEALS FLY / DRIVE CARGO DRONE

Grasshopper Air Mobility has launched its e350 Flying Cargo Van, a vertical take-off and landing drone able to transport payloads of up to 350kg, fold its wings and drive on the ground for final-mile delivery.

The Barcelona, Spain-based startup plans to have built a scaled prototype by 2026 and to start initial operational trials by 2028 with the e350.

The fully autonomous VTOL Flying Cargo Van will be capable of transporting a pallet of up to 350kg (770 lbs) over 200km (124 miles) fully electric, or 600km (370 miles) using a hydrogen-electric propulsion system at a speed of up to 220km/h (136mph).

Grasshopper's autonomous air and ground logistics system is aimed at industries with complex supply chains or high-value or high-urgency deliveries such as pharmaceuticals, automotive, electronics.

Barcelona, Spain

// HYFLUX PARTNERS WITH NEW ZEALAND RESEARCHERS

Hyflux, a UK-based startup developing lightweight superconducting motors for aircraft propulsion systems is partnering with a specialist institute from the Victoria University of Wellington.

HyFlux, which was founded in 2021 in Swansea, Wales, the Paihau-Robinson Research Institute at the Victoria University of Wellington and Wellington UniVentures in New Zealand are to work together on the lightweight motors, which feature cryogenically cooled superconductors to increase their power denisty.

Hyflux's approach uses cryogenic hydrogen to cool the superconducting motors, significantly reducing their weight. Many future zero emissions aircraft designs are opting for liquid hydrogen as a fuel source, which would provide the cryogenic conditions that the superconductors need to operate.

Wellington, New Zealand

READ MORE ONLINE

// VERTIIA EVTOL COMPLETES TEST FLIGHTS

AMSL Aero has completed the first untethered flights of its full-scale Vertiia prototype, Australia's first domestically developed eVTOL aircraft.

According to AMSL Aero since the first untethered flight earlier this month, Vertiia has been flown another 50 times.

Vertiia has been designed to fly up to 1,000km (620 miles) fueled by hydrogen at a cruising speed of 300km/h (186mph) with zero emissions, carrying up to four passengers and a pilot. AMSL Aero plans to certify the eVTOL aircraft in 2027.

The test flight was performed using remote control in the Central West region of New South Wales in accordance with Australia's Civil Aviation Safety Authority (CASA) regulations.

The company plans to begin hydrogen-fueled flight testing of Vertiia in 2025 having already broken records in 2023 by completing the first tethered battery-powered hover.

New South Wales, Australia

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RAVEN DEFENSE

RANGE COVERING REQUIRES RAVEN.

Airborne Telemetry: The Raven Advanced Phased-array Telemetry Resource (RAPTR) is a versitile, low SWAP mulit-beam antenna that is deployed on UAVs and manned aircraft. It can be adapted to11252024EOD nearly any platform, and is configuratble to meet specific mission requirments. The digital/analog hybrid architecture delivers the full band beamwidth per beam, 8-beams standard. **EAR PART 99 Exportable.**

Mobile Ground Telemetry: Raven Defense has pioneered Range-In-A-Box technology that allows for simplified, expedited range extenstion. Drive, point, and collect! The "Party Bus" mobile asset is outfitted with a 7 dB/K RAPTR array, receivers, recorders, comms equipment, SATCOM, GPS, 10kAh of batteries, and solar. Drive the vehicle out to the test support position, position the array toward the intended field of view, and in minutes you're ready to collect data and can be on station for the mission duration and beyond. **EAR PART 99 Exportable.**

Fixed Telemetry: The Telemetry And Launch Operations Node (TALON) is versitile, high gain telemetry asset that features RF Autotracking, 17 dB/K G/T (S-Band), and the the highest performance positioner on the market. It can be opitoned with swappable feeds, optical payloads, and is multiband capable. **EAR PART 99 Exportable.**

Maritime Telemetry: The Maritime Networked Test Asset (MaNTA) has been successfully supporting a range of weapon development programs for years. The fully configurable system features T-SCIFs, SATCOM, multi-band RF-Autotracking motion-stabilized, 6m antennas, FTS, optics, radar, weather balloons, and more. The Roll-On/Roll-Off design allows it to be rapidly deployed on any number of platforms and easitly transported to another theater.

Autonomous Telemetry: The Raven Defense Ghost Fleet offers flexible, cost-effective end game scoring and midcourse data collection and range safety. The USVs can be reconfigured with different senor packages; telemetry, IR and visible optics, hydrophone, and other subsurface sensors. Vessels can be launched from ship or shore, scaled in number, and configured with a blend of sensors for maximum impact.

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MICRO-CT SCANS TO IMPROVE PARACHUTES

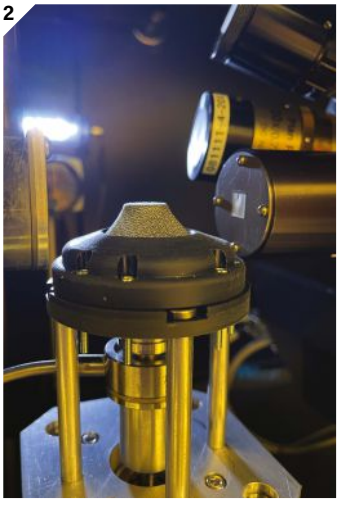
University of Illinois researcher Cutler Phillippe describes how micro-CT scanning is helping to understand how stress impacts the fibers of parachutes

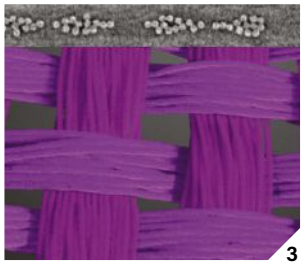
Parachutes are essential in decelerating spacecraft, delivering airdropped payloads, aiding pilot ejections, and more. Traditional methods of assessing parachute performance measure permeability and tensile strength, but recent advances in computing enable more sophisticated modeling and simulation of parachute dynamics. Modeling can reduce the cost, labor, and time needed to create mission specific textiles, by connecting fabric porosity, microstructure, and canopy mechanics to overall performance. But, the models require high-fidelity experimental data for accurate validation.

In our study, we subjected military-standard parachute textiles to radial in-plane loads in a step-wise load-to-failure pattern using a bespoke tensile testing apparatus and used micro-CT (computed tomography) imaging to examine how microstructural variations impact tensile response.
A high-precision linear actuator with 4µm steps controlled displacement and could withstand up to 120lbf.

The use of x-ray micro-CT to capture sub-micrometer details and semi-automated tools to extract data about the textile's architecture from 3D images enables a faster way to produce the data and characterize these materials.

Fabric samples were cut into 55.9mm-diameter circular coupons and imaged with a 3.7mm field of view (FOV) positioned to exclude large ripstop tows, allowing focus on the bulk weave structure. Imaging at 1.9 µm/pixel resolution with a 4× lens provided high-detail data for targeted analysis.





For image analysis, we employed a 3D U-NET segmentation technique, a method proven effective for low-contrast imaging in medical fields, to differentiate warp and weft tows – the perpendicular weave axes, in the images. Using an in-house framework, we semi-automatically extracted critical metrics such as dimensions, crimp angles, spacing between tows and pore sizes and assessed them relative to the radial stress applied.

Our findings show that the anisotropic response of parachute textiles under planar loads is strongly influenced by manufacturing methods, pretension, and the composition of warp and weft tows in terms of fiber count and size. Even with homogenous tow composition, manufacturing-induced pretension caused anisotropic behavior, with warp pretension accelerating weft decrimping under load. This resulted in weft-axis strains approximately 10% to 20% larger than those along the warp axis.

> "WE SUBJECTED MILITARY STANDARD PARACHUTE TEXTILES TO RADIAL IN PLANE LOADS"

Understanding this difference can inform processes like parachute assembly. Parachutes are made of different textile pieces that are attached to each other, and the orientation of these pieces influences properties of the overall parachute. Choosing the best parachute materials is crucial for safety and mission goals. This research can informs models which will be used to identify promising candidate textiles.

Improving models for screening parachute materials makes parachute manufacturing and applications more cost effective and time efficient. In addition to scientific missions, this work can be applied to parachutes in other settings: for instance, use in relief efforts or in recreation.

The study was published in the American Institute of Aeronautics and Astronautics Journal in August 2024. The next stage of the research is using microscopy imaging to better understand how textile pores impact airflow, as well as imaging textiles with flow passing through them to visualize the 3D deformation. \\

1 // Francesco Panerai (left), Cutler Phillippe (center) and Laura Villafañe Roca in front of the micro-CT scanner at the Beckman Institute ,the University of Illinois *(Photo : Lauren Otolski)*

2 // The tensile tester, loaded with a parachute textile *(Photo: Cutler Phillipe)*

3 // A cross-section view of a parachute textile, taken with a micro-CT scanner

MIKE MEW, DIRECTOR FOR DRAGONFIRE, MBDA UK

The testing and deployment of laser weapons is of massive importance to future air defenses. The UK plans to install its first laser directed energy weapon, DragonFire on a Royal Navy ship in 2027.

In this Q&A the director responsible for the DragonFire program at MBDA UK describes how a laser directed energy weapon (LDEW) is tested, the milestones achieved so far and the next challenges.

Laser

focus

// WHAT IS MBDA UK'S ROLE ON DRAGONFIRE?

MBDA UK is the prime contractor. We are producing the command and control system, the effects management system and handling the systems engineering and integration. This means making sure the various parts of the system go together as they should and that it satisfies the requirements as set out by our customer, including testing and verification.

// WHAT IS THE MOST ADVANCED PART OF DRAGONFIRE?

Getting the laser energy to the target has always been the real challenge. The sophisticated ways used to overcome atmospheric turbulence and keep the beam focussed precisely on a moving target many kilometers away are the most important parts of the system.

// HOW DO YOU TEST A DIRECTED ENERGY WEAPON?

On one hand, you have target vulnerability and lethality. Targets are varied and made of different materials with different surface properties – getting laser energy efficiently into the target requires a good understanding of where targets are vulnerable, and detailed understanding of laser-matter interaction.

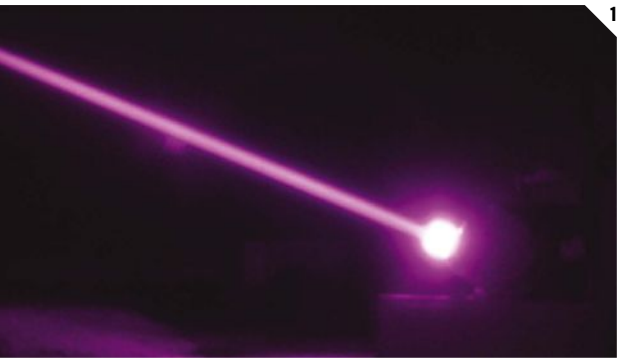
The basic approach is to take many samples of all the known target materials and subject each one to laser irradiation in various regimes. This is a slow and resource-intensive process, so improving multi-physics modeling and attempting to reproduce such tests in simulation is always ongoing.

On the other hand, you have weapon performance. How much laser energy can reach a vulnerable target spot depends on the complex and capricious nature of the atmosphere, as well as the precise functioning of all the various tracking, stabilization and correction feedback systems.

Understanding turbulence and weather effects on propagation is a large part of testing. Propagation tests are carried out with specialist instruments such as scintillometers directed across representative environments, for months or years to build up statistics – but these are limited to a single geographic location. Other organizations have used drones carrying ultrasonic anemometers to characterise the altitude variation of turbulence. All these sorts of tests help us improve and validate performance models.

There is no substitute for a complete end-to-end test of the real high-power beam over a representative distance directed at a real flying thing. However, this requires enormous amounts of preparation and extensive safety measures. Such trials are also still limited to that one geographic location, the weather conditions that happen to occur, and the particular flying thing on that day – there is no way to get a good appreciation of statistical variation without astronomical expense.

Each of these tests, whether performed by us, our partners, or by external organizations only contribute a small piece of the jigsaw of weapon effectiveness across



many possible scenarios in a complex battle setting. Our job is therefore to sift these data and build up the best picture possible.

// WHAT FACILITIES AND TOOLS ARE USED?

Subsystems are tested in the laboratory wherever possible, using emulators or simulated environments. Target vulnerability studies are conducted in laboratory settings using representative laser sources. High-power test firings can be done in the laboratory, but there are not many materials that can survive this amount of laser irradiance for long at close range, so the challenges are significant.

Operating very high-power lasers in a laboratory is much easier than outside, but because of the lack of atmospheric propagation distance a laboratory environment cannot ever test the full performance of the system. However, laser beams do not to stop until they hit something, thus, the process to test DragonFire above the horizon, as captured by the now famous photograph, marked the most significant milestone in its development history.

// WHAT HAS BEEN THE MOST DIFFICULT ASPECT OF TESTING DRAGONFIRE SO FAR?

Testing elements that benefit from full system testing in the real world is particularly challenging.

For example, designing a target tracking system that can robustly maintain the position of the spot on target is without doubt the biggest challenge. As the target heats and starts to give off smoke and particles, this can cause its optical signature to change. Even with advanced cameras in multiple bands and sophisticated image processing algorithms operating at thousands of frames per second, keeping to the desired precision – the equivalent to hitting the centre of a pound coin a kilometer away – is hugely challenging.

// WHAT WILL OPERATIONAL TRIALS FOR DRAGONFIRE ENTAIL?

A large part of operational trials will focus on understanding and communicating the important differences between it and other weapon systems – its advantages and limitations. This means testing in a wide variety of conditions. This sort of trial is essential to define weapon effectiveness and help users build up a good picture of how DragonFire fits in with other layers of defensive weapon systems as part of the larger overall battlespace.

// WHAT ARE THE CHALLENGES OF INSTALLING LDEWS ON SHIPS?

Location, size and robustness. Current Royal Navy ships were not designed with LDEWs in mind. Locating them on board requires a trade-off. They need to retain a firing arc as wide as possible to be useful, but also not get in the way of extant equipment. Additionally, they must be serviceable by power and cooling.

We are shrinking the weapon system down to fit within a defined footprint. Shaving off every cubic centimeter possible from internal systems without causing major design changes. The final aspect is working on ruggedizing the system for long-term operation at sea.

// HOW WILL LDEW SYSTEMS IMPROVE IN THE FUTURE?

A big focus is reducing the size and weight so that effective, high-power systems can be fielded on mobile land and even air platforms. Improving laser-source power density and efficiency is crucial, as well as miniaturization of other elements such as beam combining, directing optics and supporting infrastructure. \\

HOW DRAGONFIRE WORKS

DragonFire is a laser directed energy weapon that uses three apertures on its beam director to search, identify and assess potential threats. The first apertures acts like a pair of binoculars, searching for threats in a wide area.

Once a potential threat has been located the system then looks at the target through a second middle range aperture providing more detail. The final aperture acts like a telescope, and on the beam director looks like one. It narrows in on the target assessing whether there is a threat or not, and if there it provides the ultra-precision targeting required.

The beam is produced by taking raw electrical power, squeezing it down to create the laser source, then focusing and stabilizing that high-powered beam through the use of cutting edge hardware and advanced algorithms, and critically, targeting it so it is absolutely accurate and all that energy ends up precisely on the target.

That intense beam of light, then cuts through the target defeating it.

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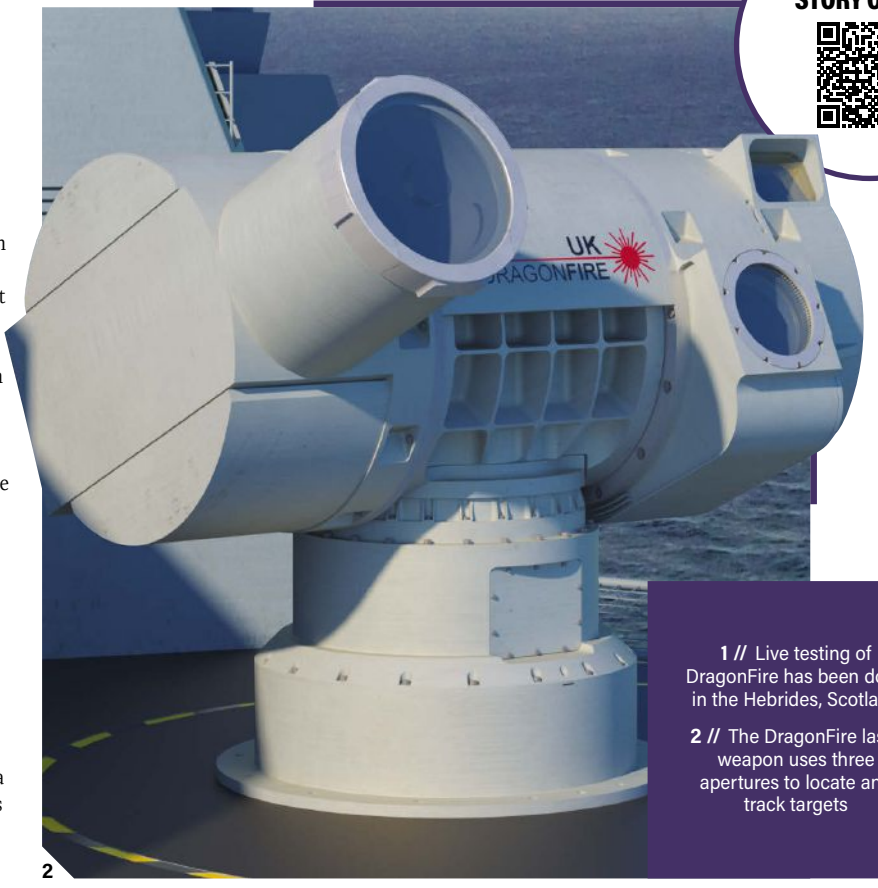

1 // Live testing of DragonFire has been done in the Hebrides, Scotland

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Five-engined Exce

1 // The Rolls-Royce FTB with the Pearl 10X mounted under the starboard wing during its first take-off of the flight test campaign on 24 March 2024
(All photos: Rolls-Royce)

Rolls-Royce's Boeing 747-200 testbed proved the perfect host to validate the capabilities of its Pearl 10X engine

After 30 flights into the six month campaign, Rolls-Royce completed flight trials with the Pearl 10X, the latest and most powerful iteration of its Pearl family of business aviation engines, in the last week of September.

The program proceeded smoothly, but with the Pearl 15 engine already powering Bombardier's Global 5500 and 6500, and the Pearl 700 installed in the Gulfstream G700 and G800, just how much testing was really required to prove the Pearl 10X for Dassault's forthcoming Falcon 10X?

Senior vice president Dassault, business aviation at Rolls-Royce, Dr Philipp Zeller oversees the Pearl 10X program. He says, "We've been successful with family platforms in the past, including the BR700 platform that produced the BR710 and BR725, and BR715 regional application. We're doing the same with the Pearl, starting with the Pearl 15 that included the new Advance2 engine core, and we built on that for the Pearl 700. The Pearl 10X is built on the same foundation so much of the core architecture and technology are the same.

"But we are integrating it into a new airframe and every airframe comes with a set of bespoke requirements.

Those drive some major differences in the installation, including all-new nacelle, build-up unit, mount system and software. With the turbomachinery, the core, we aim to minimise changes as much as possible to maintain maturity. But the Pearl 10X is our most powerful business aviation engine ever, so we've injected technology into the Advance2 core, including a new low-emissions combustor with additive layer manufacturing tiles that allow us to push the temperatures inside the engine a bit higher and still maintain compliance to emissions regulations and keep the turbine adequately cool.

"When you introduce changes you want to test how they affect engine performance and operability, which is why we test on ground vehicles and testbeds, and in flight. Nothing tells you more about an engine than operating it at high altitude."

Zeller refers to the pedigree engine, meaning the base Pearl design, and how test and certification data from previous Pearl trials were reused in the Pearl 10X effort where "the parameters were sufficiently representative".

"Some of the earlier evidence was therefore reused, but in other cases we were outside the tested parameters and needed to generate new evidence. There is little room for extrapolation but usually space for interpolation in test data," says Zeller.

Rolls-Royce has invested heavily in digital technologies, including systems that extract gigabytes of data every time a Pearl engine flies in service, plus design tools, modelling, digital twins and more. With Pearl 10X trials happening in the virtual world and on test rigs, what more was gained by taking it airborne?

"We invest massively into our prediction capability, and it helps us go into a test flight with a high level of confidence," Zeller remarks. "Usually we are flying to confirm that our assumptions and models were correct rather than to discover something. In the case of the Pearl 10X we were 100% spot-on with our predictions based on the pedigree data and performance models.

"For some testing the models are not good enough to provide the data we need. As an example, when we test against the requirements on flammable fluid drainage, even the best models we have available to us don't tell us exactly where a fluid drop will end up around the engine and nacelle. It must be tested and any areas of concern addressed. Trials help us identify weak points early and fix them, leaving this type of testing and fix until later in

"In the case of the Pearl 10X we were 100% spot-on with our predictions"

DR PHILIPP ZELLER, SENIOR VICE PRESIDENT DASSAULT, BUSINESS AVIATION, ROLLS-ROYCE

2 // The Pearl's horizontal mounting is evident as Spirit of Excellence climbs out for a test flight

3 // The Pearl 10X mounted under the inner starboard wing of the Rolls-Royce FTB. The shape of its fan blades makes an interesting comparison with the blades of the legacy RB211s outboard

"Many of the systems are common with commercial aircraft"

JOHN KNIGHT, HEAD OF TEST AND RIGS FOR REST OF WORLD, ROLLS-ROYCE

the program can require a great deal more effort."

INTEGRATED INSTALLATION

Rolls-Royce's Boeing 747-200 flying testbed (FTB) was modified to accommodate the integrated unit of Pearl 10X and its nacelle under its starboard wing, in clean air well forward of the leading edge. The Falcon 10X carries its engines in typical business set fashion, either side of the rear fuselage and the 747/Pearl 10X interface included a perpendicular mount so that the engine is carried horizontally, rather than underslung.

Zeller continues, "In the business aviation world we supply integrated powerplant solutions, which means everything that 'hooks up' to the aircraft pylon, including the engine, the engine build-up unit, the mount system, the nacelle and the software that keeps everything 'spinning'. We test all of it, so the Pearl 10X configuration we put on the flying testbed was an entire powerplant, with the intention of also testing the engine installation as closely as possible in a representative configuration."

John Knight, head of test and rigs for rest of World at Rolls-Royce confirms that the entire Pearl 10X flight test campaign was completed out of the FTB's Tucson, Arizona home base: "For some campaigns we travel to other locations depending on what we need to demonstrate. For the Trent engines, for example, we've tested in La Paz, Bolivia, for high-altitude take-offs and in other areas chasing different weather for hot and cold campaigns."

Although it is a highly capable platform, the 747 FTB cannot match the 0.925 maximum operating Mach number or 51,000ft maximum certified altitude capabilities of the Falcon 10X, meaning only the business jet can take the Pearl 10X to the limits of aircraft performance.

Zeller acknowledges the limitation but adds: "We configured the FTB so that we could test throughout most of the engine design envelope. In addition the FTB's engine fit allowed us to test at higher altitudes than a regular 747-200." Indeed, a Trent 1000 test engine replaces the port inboard RB211 on the FTB, which was therefore equipped with three RB211s, a Trent 1000 and a Pearl 10X for the latter's trials. Zeller continues, "We tested up to 45,000ft thanks to the extra power from the Trent 1000. We can also test some configurations at lower altitudes, so although we can't test the extremes of the envelope, there are some corners the Falcon couldn't reach. It would not normally fly lower down with one engine out or for relight tests, for example, but the 747

"The engine fit allowed us to test at higher altitudes than a regular 747-200"

DR PHILIPP ZELLER, SENIOR VICE PRESIDENT DASSAULT, BUSINESS AVIATION, ROLLS-ROYCE

configuration allowed us to do that down to 2,500ft."

Throughout the Pearl 10X program, the new engine performed entirely as a test article, with aircraft power coming from the RB211s and Trent 1000. The cockpit crew therefore controlled the primary propulsion units, while flight test engineers on the experimental deck managed thrust settings and other Pearl 10X parameters; ultimately, the pilots could in extremis override their inputs, taking control of the test engine for reasons of flight safety.

SPIRIT OF EXCELLENCE

Built as a 747-267B for Cathay Pacific and delivered in April 1980, the FTB was briefly held in storage during 1998/99 before being leased primarily to Air Atlanta between 2000 and 2004. Returned off-lease, the aircraft was purchased by Rolls-Royce in 2005 and named Spirit of excellence. It gained a Trent 1000 trials role in 2016 and has enjoyed a busy career, certifying every Trent 1000 variant, taking part in a variety of technology trials and demonstrations, and the Pearl campaigns – Zeller describes it as "experienced".

US company V2X operates and maintains the 747 at Tucson. "Our expertise is in the crews who operate the test engines and the experts who come onboard to conduct campaigns and collect data," Knight says, "while the aircraft element is largely outsourced." With the imminence of its 45th year of service, Knight acknowledges that spare parts are becoming a little more difficult to source, although the FTB has a useful number of flying hours left. "We have some longevity in the operation, and plenty of spare engines," Knight reports with a smile.

The FTB emerged from months of modification for Pearl trials as a five-engined 747 with two engines of different types to port and three engines of two types to starboard. How is subsequent maintenance performed on this uniquely configured 747? Knight responds, "Many of the systems are common with standard commercial aircraft so many of the maintenance procedures are the same. But there are differences and in making those changes and defining what we need to do to maintain them we contract the experts at L3. Both the Trent 1000 and Pearl installations were major capital projects conducted by L3."

The commercial 747-200 was equipped with a seldom used hardpoint under the port inner wing where a spare engine could be mounted for ferry. With the Trent already on the FTB's regular left inboard engine pylon, the ferry hardpoint was mapped across to starboard for the Pearl installation. Knight describes the modification as requiring relatively minor engineering changes, with no special structural alteration to wing ribs.

Addressing the thrust delivered by its apparently mismatched engines and the potential challenges of their very different system requirements, Knight explains, "The aircraft has several fuel tanks and there are fundamental design features in the 747 around redundancy. The Pearl engine takes the same fuel feed as the Number 3 engine - the inboard RB211 on the starboard side. Crew at control and data collection

4 // The Pearl 10X was installed on the flying testbed as a fully integrated powerplant, including nacelle

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6 // A flight engineer's station inside the flying testbed during the Pearl 10X trials

"The difficult part is modifying the aircraft and integrating it for the engine"

JOHN KNIGHT, HEAD OF TEST AND RIGS FOR REST OF WORLD, ROLLS-ROYCE

stations in the aircraft cabin are largely responsible for the Pearl, while a team, usually of two, controls the Trent 1000 as part of the flight crew."

Of course, the aircraft is extensively instrumented and multiple parameters are recorded. The screens on board are configured prior to flight to display specific parameters depending on the current test point, but all data is stored for subsequent download. No data was telemetered during Pearl trials and Knight says Rolls-Royce typically does not use telemetry during FTB trials. Zeller adds, "We are fortunate to be able to carry a lot of people. That means if a quick judgement is required on critical data, whether a test point has been achieved, then experts will be on the flight, capable of making decisions in real time."

Campaigns and test points are typically planned well in advance, the 747's capacious fuel tanks enabling repeated test points should a test fail to deliver data. However, Knight notes, "We always consider the human factors, thinking carefully about how many hours the crews work because the task requires concentration, we're after maximum quality and we're aware that people become fatigued."

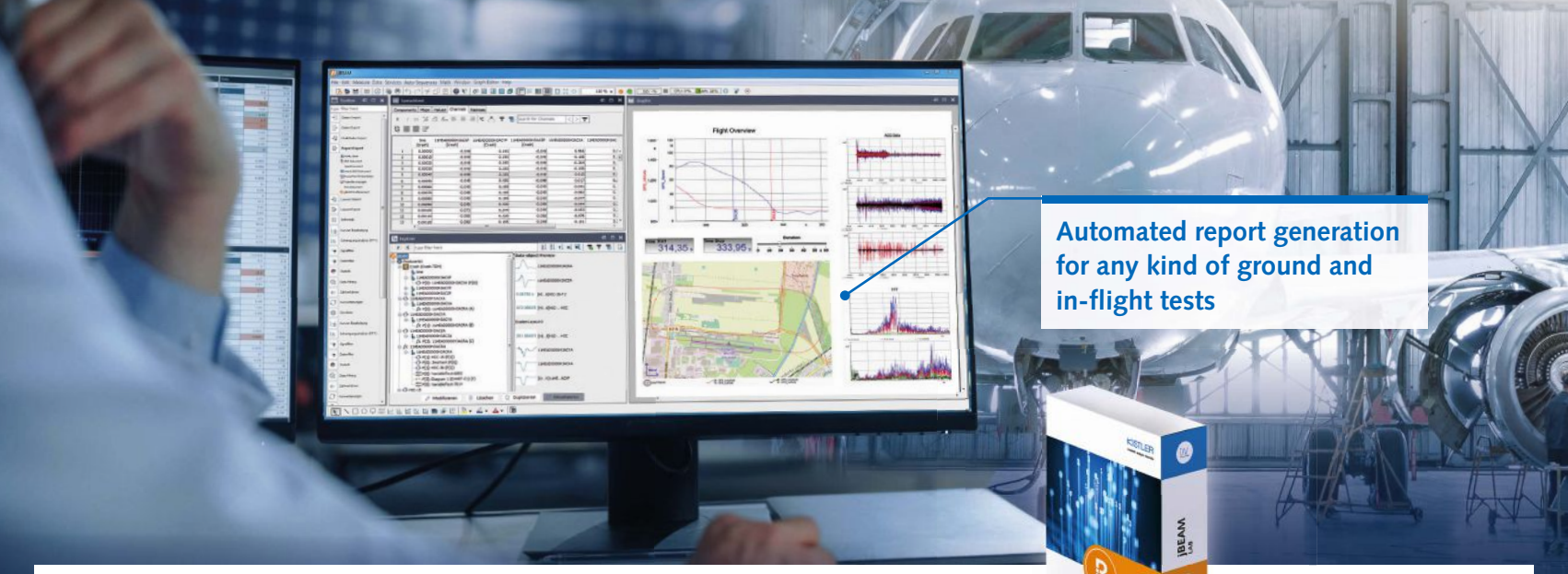
Operator stations are placed on the aircraft's main deck, typically supporting a test crew of between ten and 15 engineers.

Knight says, "There are some old airline seats left 'upstairs', but they are seldom used because we tend not to take passengers very often." The seats may be filled when the aircraft deploys away from Tucson, while its expansive holds take a range of equipment essential for the trials campaign and, if necessary, spare parts and other items.

Such remote campaigns are planned in detail long in advance, ensuring test points are understood and the people and resources needed to achieve them in place. Knight says for overseas deployments requirements including visas and work permits add another essential planning element. He continues, "Typically, a campaign like this would be around two weeks, during which we're unlikely to fly every day."

The Pearl installation has enabled the testing of a business jet engine on what was previously a platform dedicated to large commercial engines. Referencing the Trent 1000, Knight concludes, "We've already trialed three variants of Trent 1000 in three separate campaigns. The installation was common, the engine different but the aerodynamic line the same, so subsequent programs really depend on what level of change and which additional test points are required.

"The difficult part is modifying the aircraft and integrating it for the engine, and the same is true for the Pearl." For now, the Trent 1000 is likely to remain in place while Spirit of Excellence awaits its next campaign. \\



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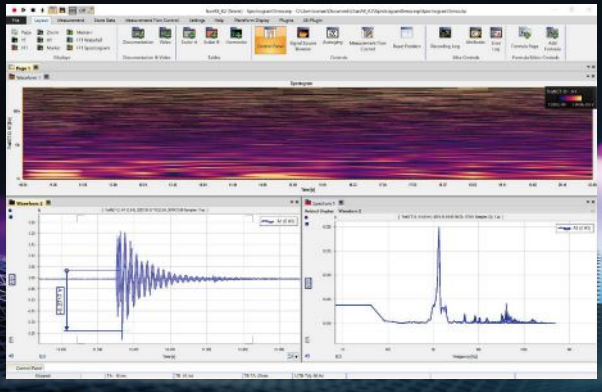

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Digita
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Digital twins are proving their usefulness across the aircraft lifecycle from development to operations

Digital twin technology is revolutionizing many industries, driving down costs, speeding up projects and helping to increase innovation. Companies in the aerospace sector are becoming aware of how a more digitized approach to programs can result in positive changes.

It is why there is a huge interest in digital twin technology. A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity – allowing an infinite amount of testing to run without the cost and time involved in more traditional approaches.

The technology can be used to recreate digital versions of entire aircraft, specific sub-sections or even individual components to better understand them.

The race to push the boundaries of what digital twin technology can achieve is pulling in research universities and the some of the largest companies in aerospace. Huge investments are being made across the world to develop digital tools and processes that can deliver the next advances in aerospace technology more efficiently and effectively.

ACCELERATED PROGRAMS

In the UK, Digital Catapult is part of the Digital Twin Consortium that is working to create the UK Digital Twin Centre in Belfast, Northern Ireland. The Digital Twin Centre is due to open its doors in early 2025. The program is receiving £37.6 million (US$47.5 million) of funds from regional and national governments, with co-investment from Thales UK, Spirit AeroSystems and Artemis Technologies.

Steven Wood, head of aerospace, defence and security at Digital Catapult says, "The development of the Digital Twin Centre isn't just for aerospace, but we see aerospace as being the driving force behind it. It is a national facility to make UK industry more competitive," he says.

When it's operational the Digital Twin Centre will help drive forward the use of the technology, and build

1 // Detailed digital twins of factories can help improve efficiency by realistically modeling different setups and manufacturing flows

on the work that is already taking place in the aerospace sector.

"We have already seen quite a few examples of digital twins. Rolls-Royce has done a lot of pioneering work creating simulated models of their latest engines," says Wood. "Some large aerospace OEMs have even modelled every physical system of an aircraft in a way that mimics the physical world as closely as possible.

"They have created a test rig for a physical system, for example the actuators on a modern fighter jet, and then created a digital twin of those actuators. They have operated them side by side and measured the response and performance of each, and then narrowed that gap as much as possible so that the digital twin behaves exactly like the physical equivalent."

This kind of approach could help aerospace companies improve the way they operate, impacting everything from innovation to manufacturing, speed of development and maintenance.

"When you are developing a product, traditionally you are building prototype versions of the product itself and every one of its systems. But as these things become more sophisticated the time it takes to develop them increases. You've seen some projects like the F-35, take much longer than they should have done," says Wood.

It is projects like these that Wood believes digital twins will have a transformative effect on.

"What if a development stage doesn't need to have a physical realization and a twin can be tested and stressed and shown to be fit for purpose in a digital environment?" he says.

It is a perhaps obvious but logical use. Each time a physical system doesn't have to be created a significant amount of time and resources can be saved. When integrated systems or an entire aircraft are being tested in the real world, the process takes a long time. Digital twins can help reduce the number of prototypes needed. That also means reducing the amount of prototype tooling too.

"It adds up to a significant saving in both time and cost – for the client and for the company making it," says Wood.

"What if a development stage doesn't need to have a physical realization and a twin can be tested in a digital environment?"

2 // Steven Wood, head of aerospace, defence and security at Digital Catapult

There are already important programs the technology could be used on. The use of digital twins could help the Global Combat Air Programme – the UK, Italy and Japan's shared endeavor to develop a next generation fighter aircraft – to reduce the time and cost of the project by half according to Wood.

MANUFACTURING EFFICIENCIES

Siemens Digital Industries Software is committed to driving digital twin technology's integration into aerospace programs. It is supplying its Siemens Xcelerator portfolio of industry software to US aerospace startup Natilus.

As part of the collaboration Natilus has used Siemens' NX immersive designer to combine the real and digital worlds using a Sony XR Head Mounted Display. Natilus has used the technology to take a model from a 2D screen to a full-scale

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3/4 // US-based startup Natilus is using Siemens Xcelerator software to create and manipulate digital twins during the development of its blended wing body cargo aircraft *(Photo: Natilus)*

85ft (26m) wingspan immersive digital twin that is viewed inside a hangar.

But Siemens does not only see digital twins as a tool for development programs. The company believes the technology can be a key part of making sure that once an aircraft, or its components and parts enter production they meet the stringent requirements needed by the aviation industry.

Siemens Digital Industries Software's vice-president for aerospace and defence, Todd Tuthill says, "Digital twins become even more powerful in manufacturing. I can understand what the most efficient way to build a factory is by building a digital twin.

"They can help me to understand what machine I should purchase and figure out the most efficient way to move products through the factory."

Once up and running there are also benefits. According to Tuthill you can continuously feed data from the factory floor into a digital twin to help streamline processes, improve efficiencies and overcome issues including machine downtime and supply chain problems.

"You could run all those what if scenarios on the digital twin and then take them out and implement them in the factory. So, digital twins can make the process of manufacturing much easier and improve efficiency," says Tuthill.

4

MAINTENANCE TARGETS

Aerospace is becoming increasingly focused on its environmental responsibilities too. New forms of propulsion could help it meet targets, and digital twins will play an increasingly important role.

The University of Nottingham in the UK has recently signed a memorandum of understanding with simulation company Altair to help it develop a digital twin to rapidly design, validate and test electric propulsion systems in aircraft and advanced air mobility vehicles.

While there are many challenges to overcome before electric powertrains are commonly used by aircraft, researchers at the University of Nottingham are already considering how digital twins can help improve electrified powertrains once they enter service.

"Digital twins can make the process and efficiency of manufacturing much easier"

5

5 // Todd Tuthill, Siemens Digital Industries Software's vice-president for aerospace and defence

Tao Yang, professor of aerospace electrical systems at the University of Nottingham says, "For future electric or hybrid-electric aircraft there is a large energy storage requirement. And with batteries we can help predict the maintenance schedule with digital twins."

Existing propulsion systems are maintained to a set schedule and engineers physically inspect different components. However, batteries and motors are closed systems, so as Yang says, you cannot open them up in the same way to see how the copper is behaving.

Yang sees twins as linked by a thread between the ,physical and digital twins that carries data. When more data is constantly being fed into the system it should be able to better predict when there could be an issue – with a motor or a battery – and recommend preventative maintenance.

PREDICTIVE FUTURE

Digital twins could help remove the guess work sometimes involved with an aircraft's operational life, especially when

6 // PhysicsX has used digital twin technology with an aero-engine supplier to reduce waste in its turbine blade manufacturing process *(Photo: PhysicsX)*

linked to artificial intelligence. Startup PhysicsX is building artificial intelligence models for accurate physics simulation. The AI models enable a generative engineering technique that help to accelerate time-consuming activities and streamline engineering processes.

Neil Cameron, principal engineer at PhysicsX says, "We train AI to predict the outcome of a digital twin simulation rather than running the base simulation. The AI provides answers that are the almost the exact equivalent of traditional testing methods, but in less than a second."

This machine learning approach can be used to predict the output of anything from a component's drag to its life expectancy. The technique is not theoretical, PhysicsX has already put the AI-powered technology into practice. It is working with a company that produces aero gas turbines. Use of the technology has helped to significantly reduce wastage in certain parts of the manufacturing process.

"The company was putting 30,000 parts per year into quarantine for further work to decide if they were any good," says Cameron.

"Essentially, they were taking each [turbine] blade with its complex shape, 3D scanning it and comparing the scan to their model." If it was out of tolerance the blade would be scrapped.

"The digital twin work we did essentially modeled how much air a given shape of blade transports through the engine," says Cameron.

"If you get a blade out of tolerance, the answer the customer really needed was, how much air is it going to move? Am I going to be 10% down, 5% down, or is it going to be an insignificant amount?"

"We train AI to predict the outcome of a digital twin simulation rather than running the base simulation"

7 // Neil Cameron, principal engineer at PhysicsX

PhysicsX trained an AI-based model to predict the lift and drag of a blade. Key was that the system didn't take hours to run, instead, they were getting answers in seconds.

"Something comes off the line, they scan it, they see it's out of tolerance. They can then answer the question, what would the performance be if we integrated this into a gas turbine," says Cameron. "They found that there was a much more nuanced picture, and tolerance was more about performance than about a geometric measurement."

Digital twins are receiving a huge amount of attention, and importantly investment. The UK Digital Twin Centre based in Belfast will be joined by another center being created at the University of Nottingham – and no doubt far more in the UK. But there is also investment in the USA by big players including Lockheed Martin. And at some point it is hoped that different centres could speak with one another and collaborate.

Fully integrated into the aerospace sector, digital twin technology could help drive innovation, reduce costs and speed up programs, from initial concept phase, all the way through to continuous maintenance. It could be an incredible shift for an industry that has often suffered from program delays and constantly expanding budgets in the past. \\

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High in hydrogen R&D

A multimillion program of work is transforming Cranfield University into one of Europe's leading hydrogen aviation research hubs

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This simulator at Cranfield's Aerospace Integration Research Centre developed with Rolls-Royce has been used to simulate and test the cockpit of a possible hydrogen-fueled aircraft *(All Photos: Cranfield University)*

"The main question is how will a change in propulsion impact the shape and design?"

2 // Mark Westwood, professor of aeronautics at Cranfield University

3 // The UK's National Flying Laboratory is based at Cranfield University's airport on campus

4 // Declan Saunders, research assistant, Cranfield University

Cranfield is a postgraduate-only research university located in the rolling hills of Bedfordshire an hour's drive north of London. Founded in 1946 at a former WW2 airfield, to this day Cranfield is the only European university with its own airport.

As an aerospace-orientated university, Cranfield has to move with the times. It only attracts grants, industry investment and students if its experts, courses and research projects are at the forefront of innovation.

Around Cranfield's campus, major construction work is happening now for new testing sites and laboratories, that will add vital new capabilities to help develop zero emission aircraft fueled by gaseous and liquid hydrogen.

LOW CARBON TRANSITION

In April 2024 the University won £69 million (US$90 million) for the CH2i (Cranfield Hydrogen Integration Incubator) program. This was the largest amount of funding Cranfield has ever won for a single project. The money is being used to build several new buildings and test facilities dedicated to researching hydrogen engines, sub-systems, fuel systems and storage.

John Horsley, hydrogen special projects manager at Cranfield, is overseeing the CH2i build program on campus. This involves liaising with supporting partners and researchers as well as booking the projects that will happen in them.

Thanks to a background that includes work in the automotive industry he recognizes that there are aspects of powertrain development that are common between that sector and aerospace. But key differences do exist. He says, "There are different requirements, such as vibration and the operating environment. The packaging requirements are also challenging in an aircraft.

"Taking liquid hydrogen and sending it through pipes, valves, and pumps means we have to look at embrittlement and the effects of cryogenic temperatures. The challenges are immense."

"CH2i will be the first large-scale hydrogen research hub dedicated to solving these types of technical challenges around hydrogen's use as an aviation fuel and helping to scale up its production and use."

NEW BUILD

Cranfield's new Hydrogen Integration Research Centre (HIRC) is an extension to existing laboratories and will host low TRL work. A new research center is also being constructed that will contain several new 50-square-meter test cells. Each cell will hold different experiments

ONEHEART PROJECT PIONEERS NEXT GENERATION AIRCRAFT DEVELOPMENT TOOLS

The £26 million (US$34 million) Out of Cycle NExt generation highly efficient air transport (ONEheart) is a three-year Airbus-led project, that is part-funded by the UK Government and aims to develop the design and simulation tools and technologies to develop future aircraft. The ONEheart team is at the stage of validating the software tools and works at the Agile Concept Laboratory inside Cranfield's Aerospace Integration Research Centre.

Professor Mark Westwood, professor of aeronautics at Cranfield University works on ONEheart and says, "The main question about the next generation of aircraft is what will the propulsion be and how will a change in propulsion system impact the shape and design?

"When you start considering alternative aircraft shapes the tools are not validated like they are for existing designs. There is more uncertainty, which makes the development lifecycle longer. Plus, we need to explore a wider range of concepts."

"We are developing tools and ways to accelerate the design process. The tools simulate things like handling qualities and flight dynamics," says Dr Estela Bragado Aldana, research fellow in flight modeling and simulation at Cranfield.

Different physics simulations are applied to the 3D computer models to predict performance and handling. The results are combined with real-world flight data gathered from Cranfield's flying testbed aircraft, a Saab 340. The models are then flight-tested in a simulator, where feedback from a pilot is incorporated into the design process. "The feedback could be that the aircraft is sluggish or the stability or roll response is poor," adds Aldana. "Flight testing early in the design stage digitally allows us to iterate faster."

2 // Artist's impression of one of the new test centres being build under the CH2i program of work and due to open during 2025

2

that use gaseous hydrogen. The HIRC and the new test cells will be equipped for handling gaseous hydrogen.

"The rooms in the research center are open and not designated to any particular purpose. There will be sub-system setups, such as fuel systems and tanks. The bigger tests with turbines will be done at a test area on the edge of the campus, where we can evacuate more easily if necessary. A lot of the tests will be in the open or under Dutch barns," says Horsley.

Hydrogen research currently happening at the engine testing area, such as a program looking at low NOx hydrogen combustion, is to be moved to the HIRC. This will enable the engine testing area to be reconfigured with CH2i funds to host all future liquid hydrogen (LH_2) experiments and tests.

"If they need any liquid hydrogen in the labs we will transport small amounts there in a dewar," says Horsley.

CH2i funding is also paying for a project to modernize Cranfield's airport. This is the most expensive work package because it requires groundwork and repairs to the runway surfaces.

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LOOKING FORWARD TO HYDROGEN AIRCRAFT COCKPITS

A recent project at Cranfield's AIRC has developed a fixed base simulator to explore the human factors aspects of future hydrogen aircraft. The cockpit model is based on an A320's, but with added touchscreens and glass. "The simulator is a basic interpretation of what the dashboard and cockpit of a hydrogen aircraft would look like," says project lead Declan Saunders, research assistant transport systems, Rolls Royce Future Flight Simulator at Cranfield University.

The project has recreated scenarios such as failure modes including fuel pump failures. This type of information needs to be supplied to the cockpit and pilot efficiently and effectively.

"We are looking at how do we put information into the cockpit quickly and display it simply when the pilot has very little time to deal with an incident," says Saunders.

Another area being examined is new systems and functions. For example, nitrogen is needed to purge the aircraft's fuel system before and after each hydrogen refuel. Startup procedures for a hydrogen aircraft will also be radically different – the fuel is kept at -253°C and the aircraft is likely to be attached to a ground conditioner.

The project finished in September 2024 and a report was submitted to Rolls-Royce in November. "We want to represent hydrogen aircraft to the industry and regulators to show they are a safe possibility," Saunders adds.

"The challenge with liquid hydrogen is that it is supplied in units of two tons"

FUEL PRODUCTION

A main aim of CH2i is to establish the production of LH2 on-site at Cranfield for use in testing. A green electrolyzer is being built on campus to generate gaseous hydrogen from water. This hydrogen will go to a liquefaction plant at the test area to make LH2. Production capacity will be 50kg (110 lbs) a day, with a 250kg (550 lbs) buffer tank. Cranfield is in the process of sourcing a supplier for the liquefaction plant.

"The challenge with LH2 is that it is supplied in units of two tons, mainly from Rotterdam. If you want 250kg for an experiment, which is the kind of amount we usually require, you end up throwing seven-eighths of it away," says Horsley.

There are several industrial partners for CH2i, including hydrogen processing and production companies and aviation. Ground has been broken for the HIRC and research center buildings, sites are being cleared and planning permissions applied for the other areas. The HIRC and the research center will be open and running by summer next year.

"All of the hydrogen test cells have been booked for when we open already. Some are taking experiments that are already running in the existing test area, but there are several new experiments," says Horsley.

RESEARCH FOCUS

In total, £100 million (US$130 million) of R&D projects are being hosted at Cranfield over the next eight years. A large chunk of that is capital spending on CH2i. The second largest is £14 million (US$18 million) to set up a doctoral training center for PhD students. The centre will ready post-grads to work in industry on hydrogen and electrification technology projects. The center will help academia and the aviation industry transition to working with hydrogen and electrical technologies.

The first projects to use facilities built under CH2i will include the build and test of liquid hydrogen tanks and fuel systems. They will address the challenges around leakage that hydrogen poses, and develop lightweight materials for the tanks and pipes. Experiments will consider different fuel system architectures and layouts, sensing technologies for inside of the tank and advanced pumps.

Thermal management and control is another big challenge for hydrogen, as is the development of hazard control and mitigation strategies. Numerical research projects aim to understand cavitation in liquid hydrogen pumps, and the implications that unsteady flow will have on performance in LH2 fuel systems – bubbles, slugs and mist in the hydrogen flow.

The performance of the hydrogen tanks and fuel systems will be tested in negative or zero *g* conditions on with drop tests. Some tests will be done off-site at locations more suitable for riskier tests. "There is only so far you can get with numerical modeling. You need experimental data and validation eventually. That can happen thanks to CH2i, at all the different TRLs from material up to aircraft level," says Professor Bobby Sethi, head of low emissions technologies and combustion group, centre for propulsion and thermal power engineering and chair of Cranfield University's Hydrogen Strategy Committee.

"We have projects on campus working with liquid hydrogen and cryogenics, materials, storage tanks, gas turbines, low-NOx combustion, infrastructure and ground operations. They involve major industry players. CH2i enables the delivery of some of these ongoing experimental projects and will enable new projects."

5 // The Aerospace Integration Research Centre hosts several hydrogen R&D programs

6 // Professor Bobby Sethi is the Chair of the Cranfield University Hydrogen Strategy Committee

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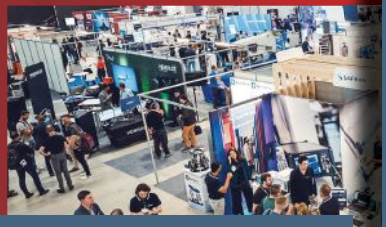

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7 // Inspection technologies are tested on Cranfield's 737-400 at the Digital Aviation Research and Technology Centre's hangar laboratory

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"Only a gas turbine has the far superior power-to-weight ratio needed for longer flights"

PHASES OF HYDROGEN

Sethi predicts a phased introduction for hydrogen aircraft. The next 10 to 15 years will demonstrate their viability, safety and closely involve certification bodies. "You can't compete with kerosene aircraft during this phase, so we will need financial support from government," he says.

The second phase will start in around 20 years and will see the focus shift to improving the efficiency of hydrogen aircraft. It isn't until more than 30 years from now that hydrogen aircraft begin to rival tube and wing kerosene aircraft in terms of efficiency, Sethi believes.

He also sees tackling decarbonization of long-distance flights with alternative fuels such as gaseous hydrogen as a high priority. 70% of commercial departures are for flights that are under 1,000 miles (1,600km), but these only represent 30% of aviation's total fuel burn.

"A fuel cell large enough for longer range flights will, like a battery, be too heavy. Only a gas turbine has the far superior power-to-weight ratio needed for longer flights," says Sethi.

FLIGHT TESTING

Cranfield's airport will be used for flight tests and operational trials of hydrogen infrastructure and ground support equipment. Nearby firm Cranfield Aerospace, which is modifying a Britten Islander with an LH2 fuel cell hydrogen propulsion system will use the airport for propulsion and fuel system tests and the first flight of the aircraft.

"We are spending a lot of time helping the CAA develop regulations and health safety guidelines. We work with them and Cranfield Aerospace on the testing side," says Horsley. "The first things that have happened are in ground support equipment and on the operational aspects of hydrogen. That includes refueling, which technically is possible, but the CAA has to be satisfied it is safe."

C2Hi is critical for the future of Cranfield and the UK to stay relevant in the industry argues Horsley: "It is essential we can accommodate hydrogen testing because it is the direction the aviation industry is moving in," he says. "Cranfield has a role to play in enabling hydrogen as an aviation fuel, working with the large companies, ensuring they can do their R&D here and so keep their operations in the UK.

"CH2i is a great start, but it takes up to 15 years to build a clean sheet design for an aircraft. We have one design cycle left before we need to hit net zero. It's a challenging goal."

Cranfield University has been involved in many of aerospace's technology developments over the decades. The provision of testing facilities for hydrogen-fueled aircraft reflects another shift for the aviation industry and the makeup of Cranfield's campus. \\

8 // John Horsley, hydrogen special projects manager at Cranfield University

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9 // CH2i will provide several new laboratories for hydrogen testing

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// GRAHAM JARVIS

Engineers are testing the materials and processes needed to produce parts for spacecraft while in space, extending the life and range of missions

Going Galac

1 // The Galactic 07 mission during the boost phase of flight in June 2024. The SpaceShip carried experiments to test the viabilty of materials and 3D printing processes in space *(Photo: Virgin Galactic)*

ctic

Mankind has always pushed at its boundaries – to go where nobody has gone before. Today, the ambition is to explore the opportunities that may be present in space and on other planets.

When things go wrong with terrestrial aircraft, they can land and be fixed, tested and returned to operational service. Parts are mostly available whenever they are needed. However, repairing and maintaining spacecraft – whether in orbit or on a deep space mission – is a far more complex proposition. To carry out maintenance there is a choice – either carry all the tools and parts required or use technologies such as 3D printing, also known as additive manufacturing, to make the necessary spare parts and tools in space.

3D printing also offers an opportunity to develop a space-borne manufacturing industry in space. To understand how this can be achieved, and to improve the available technology, test flights are being undertaken around the world– particularly in the USA and in Europe.

On June 8, 2024 from Spaceport America in New Mexico, the Virgin Galactic 07 mission transported two payloads from the University of California, Berkeley and Purdue University into suborbital space to conduct 3D printing tests.

2 // The Cygnus spacecraft for the NG-20 cargo mission to the ISS launched from Cape Canaveral Space Force Station in Florida in January, carrying the ESA and Airbus metal 3D printer *(Photo: Northrop Grumman)*

"To address critical capabilities needed for space exploration, researchers must advance their technologies as quickly as possible"

DANIELLE MCCULLOCH, PROGRAM MANAGER, NASA'S FLIGHT OPPORTUNITIES PROGRAM

RESEARCH PROJECTS

Berkeley University's 3D printer SpaceCAL spent 140 seconds in suborbital space in microgravity aboard Virgin Galactic's VSS Unity spaceplane, during which time it autonomously printed and post-processed four test parts from a liquid plastic called PEGDA to assess its usefulness in space.

On the same flight, Purdue University's experiment studied how the sloshing of liquid propellant affects a spacecraft's direction to determine the time needed for liquid propellant to settle. The rotational slow experiment models the effects of spacecraft rotation on liquid and gas in the propellant tanks.

This may occur when a spacecraft docks with, for example, a space station, causing the liquid to accelerate when it stops. It can happen in a fuel or water tank, a life support system, or in liquid containers for 3D printers.

Professor Steven Collicott from Purdue University's School of Aeronautics and Astronautics says, "If the tank is 100% full of liquid or 100% full of gas, then there is no slosh."

In zero gravity sloshing when a liquid moves up one side of a tank, gravity doesn't pull it back down. For the liquid to settle capillary physics is needed, where the wetting of the liquid on the solid surface and the surface tension of what Collicott calls the "liquid-gas interface" moves the liquid back into the equilibrium position.

3 // The first metal part ever created in space. The 9 x 5cm product, along with three others planned during the rest of the experiment, will return to the Earth for quality analysis *(Photo: NASA / ESA)*

EVOLVING DESIGNS

Data from experiments like this inform spacecraft design. Sloshing liquids have safety implications because in zero gravity it can cause a spacecraft to move back and forth in highly unstable ways, leading to accidents that could be avoided.

NASA works with several industry flight providers to demonstrate technologies for space exploration, discovery, and the expansion of space commerce. To launch the researcher and their equipment they use suborbital launch vehicles – rockets – that reach high altitudes and may include periods of microgravity.

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4 // This full-scale model of a tank with a damping internal diaphragm was used on the New Horizons and Deep Impact spacecraft to study the effects of fluid motion in spacecraft propellant tanks *(Image: SWRI / NASA)*

The flights can also use a modified aircraft to achieve 15 to 30 seconds of reduced gravity through a series of up-and-down maneuvers called parabolas. Parabolic flights can be used for testing technologies that need to operate in space or planetary environments, including lunar and Martian gravity. Lander vehicles that specialize in testing entry, descent, and landing technologies are also deployed.

NASA's Flight Opportunities Program also supports flight testing on high-altitude balloons. These large balloon systems reach altitudes of about 30km (98,000ft) and typically sustain the longest duration of the suborbital vehicles, hours, days, or even weeks at a time. This suits them to experimental payloads that require extended periods of data collection.

Danielle McCulloch, program manager of NASA's Flight Opportunities program says, "To address the critical capabilities needed for space exploration, researchers must advance their technologies as quickly as possible.

"Our program enables them to rapidly move from the laboratory to flight test, and in many cases multiple flight tests across different vehicles. This allows them the opportunity to learn from initial tests, implement improvements, and then fly again."

3D PRINTING POTENTIAL

Taylor Waddell, a pathways engineer at NASA and a PhD student at UC Berkeley heads up the SpaceCal project. He says that 3D printing could have many different uses in space. For example, an astronaut might need a dental crown, which could be made with a 3D printer.

He says, "We have demonstrated 60 different materials, making items such as nuts and bolts, structures, electronics casings, and other parts with this printer. We have silicones, hard acrylics, biogels, metal and glass printing capabilities. For example, SpacCal can make seals. Our focus has been on reducing mission risk as much as possible."

Anthony Moody, a former researcher on the SpaceCal project says the team is happy with the results from the 3D printer. He primarily worked on its mechanical design, which focuses on the way geometries are achieved by rotating three parts. "A certain wavelength of light from a projector is used to activate the photo resin," he says.

Researchers are using data from SpaceCal testing to analyze the accuracy of geometries and the quality of the printing. The data also shows the performance of the automated system.

Moody emphasizes that the team cannot obtain this data from terrestrial testing, making the microgravity data invaluable. It helps improve parts of the printer's design, such as the decision to add more vibration isolation.

Moody says, "We can then work out the cause of it for the next iteration. We aren't restricted legally, but the research group likes to keep their public information controlled. You want to test in a controlled manner environment, and that's the only way to achieve this."

5 // This Spinning Slosh Test Rig was used by engineers to test fluid dynamic effects in models of spacecraft fuel tanks *(Image: SWRI / NASA)*

5

EUROPEAN PRINTING

The application of 3D printing in space is also being tested by the European Space Agency (ESA), under contract by Airbus Space and Defence. Its printer uses metal for 3D printing, and it could be deployed to help maintain the International Space Station (ISS), a lunar base, a Mars habitat, or a commercial platform.

Rob Postema is from the ESA's Low Earth Orbit (LEO) Exploration Group and is part of the team which during August 2024 printed the first 3D metal shape in space onboard the ISS. The metal printer in the ISS can print shales within the dimensions of a soda can.

Testing of the 3D printing process has involved verification of crew and ground procedures to operate the printer, and close monitoring of the printing process. The

ZERO G 3D PRINTING MOVES BEYOND THE LAB

CosmicMaker, UK-based 3D printer-maker Photocentric's patented printer for zero gravity environments has been tested by full contra-rotational 360° movement in the laboratory. It is now moving to the next step, printing in simulated zero gravity, which will be achieved in a rocket or spaceplane.

The printing process will take place continuously throughout the brief window of microgravity. The printed part will be examined back on Earth to see how it performed under near to zero gravity conditions.

Photocentric has successfully printed highly accurate objects using their patented Liquid Crystal Display (LCD) driven process which uses monochrome LCD screens, specifically created for 3D printing. One innovation is to use visible light curing polymer that enables far greater light to be emitted through the screen and create more curative energy.

The longer wavelength light is also better at curing in particle-rich formulations. With 10in (25cm) LCD screens, and a resolution of 22 microns, the 3D printing leaves the final parts looking like injection moulded ones. Although successful on Earth, printing in the company's rotational jigs doesn't necessarily mean the process will be successful in space, so the first flight test represents a key milestone for the company that Photocentric's space team is confident will be achieved.

6 // Astronaut Andreas Mogensen after installing the Metal 3D Printer on the International Space Station *(Photo: NASA / ESA)*

Q: HOW DO YOU FLIGHT TEST A 3D PRINTER DURING A SUBORBITAL FLIGHT?

A: In a similar way to traditional space flights. We develop requirements. The power we need, what forces exist, what we need to survive.

We then design the printer to meet those requirements, and move from the development phase to testing and the experimental side. Eventually, it's about how the device will fit into the spacecraft and the launch.

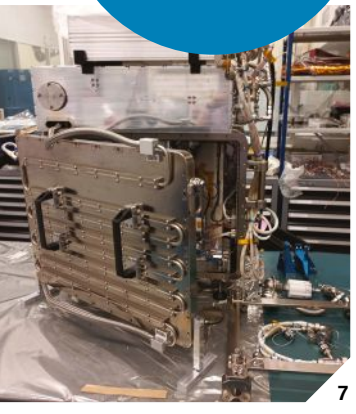
For us a challenge was about funding when establishing the requirements. The project also had to happen within nine months. It's mostly about making sure things are done right in the time you have. Normally these experiments take around two years to do.

There are many different fields of engineering coming together on a project like this, such as electronics engineers, optics engineers, structural engineers, chemical engineers, and material scientists. It's essential to have these different skills.

Partners are important as well, they bring a lot of outside thought. You go through review stages, whereby partners review your processes while keeping a bit of distance.

The rate at which 3D printers are being used is going to keep growing as they are such a useful tool for space exploration. The use cases will keep growing as the processes are better understood in microgravity.

– Taylor Waddell, pathways engineer at NASA, PhD student at UC Berkeley and project leader of SpaceCal



7 // The flight model of the 3D metal printer sent to the International Space Station in January *(Photo: ESA)*

printing is done in layers, and each layer has a photo taken of it to understand the quality achieved. At the end of the printing process they get printed samples, which are analyzed upon the return to Earth to see if they are accurate and strong enough.

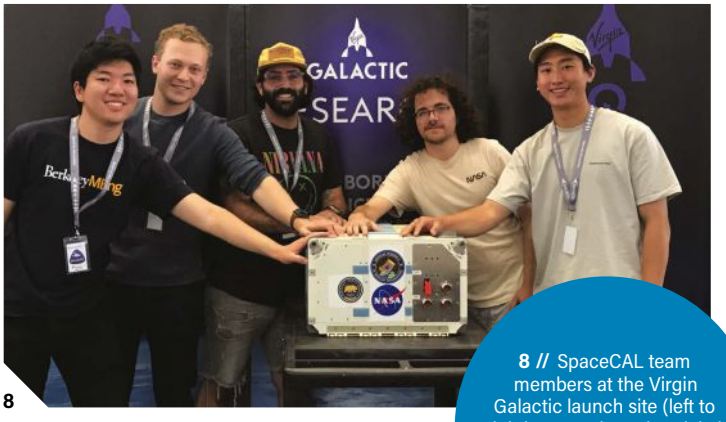
According to Postema sub-orbital flights provide minutes of microgravity, whereas on the International Space Station, the benefit is continuous microgravity. This is crucial because printing the first samples with the metal 3D printer took 25 days. Printing only occurs for four hours a day because of the noisiness of the printer. When in Low Earth Orbit, Postema says more can be done in comparison to when it operates in a suborbital environment.

He considers one of the next steps to be using artificial intelligence and machine learning to largely automate the printing process, which can be controlled remotely from Earth. He believes that one of the main challenges for engineers is to find the right balance between automation, activities by crew, and remote operations for 3D printing in space. As these projects are still quite nascent, there is still much to learn from the data samples provide when brought back to Earth.

GROWTH POTENTIAL

Yet Waddell believes 3D printing in space will become commonplace because there are more private space stations being planned, including lunar and Martian habitats. 3D printing enables the production of things that people can't predict before a mission and will be instrumental in creating permanent extraterrestrial bases. Meanwhile, the rate at which they are being used will increase because they are "such a useful tool for space exploration".

While the analysis and research aren't complete, the number of use cases for 3D printers in space will grow, and new industries might be born with it. Yet what will need to remain paramount is flight, astronaut, and research crew safety. \\



8 // SpaceCAL team members at the Virgin Galactic launch site (left to right): Sean Chu, Jake Nickel, Austin Portinause, Taylor Waddell, and Brian Chung *(Photo: Virgin Galactic)*

"We have demonstrated 60 different materials... we have silicones, hard acrylics, biogels, metal and glass printing capabilities"

TAYLOR WADDELL, PATHWAYS ENGINEER, NASA & PHD STUDENT AT UC BERKELEY

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// PAUL WILLIS

Algorithmic vis

// Daedalean's visual capture unit is inside a pressurized container to protect it during flight *(Photo: Daedalean)*

Companies are using advanced camera systems and radar to fulfil the ambition of fully autonomous aircraft

Slowly but surely the dream of fully autonomous flight is getting closer. In the USA, the Federal Aviation Administration is putting the finishing touches on its beyond-visual-line-of-sight regulations, with a draft of the Part 108 rule expected by the end of the year. At the same time, European Union member countries are gradually giving out permits so more drone developers can operate their aircraft out of sight of pilots.

But for beyond-visual-line-of-sight (BVLOS) operations to really take off requires the development of robust and reliable detect-and-avoid software, an on-board system that can see and respond safely to its airborne environment in real time. There are different approaches among unmanned aircraft systems (UAS) developers about the technology underpinning these systems, but many are creating systems that rely in whole or in part on camera-based computer visioning.

DATA CLOUDS

As with similar software developed for self-driving cars, these camera-based systems rely for their efficacy on large volumes of data to train algorithms that can see obstacles in the environment. To this end, NASA researchers have recently developed a camera pod with

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the goal of creating a data cloud that UAS developers can use to train their detect-and-avoid systems.

The pod was developed and built at NASA's Armstrong Flight Research Centre in Edwards, California, and is called the Airborne Instrumentation for Real-world Video of Urban Environments (AIRVUE). The device was tested this summer on a piloted helicopter at NASA's Kennedy Space Centre in Florida.

According to Nelson Brown, lead NASA researcher on AIRVUE, the catalyst for the project came from researchers at NASA's Ames Research Centre, who were looking for real world datasets for the development of systems for advanced air mobility.

Brown and his team started providing the researchers with approach and landing data using their drone hardware, but soon they realized that they required "a custom pod that used bespoke hardware to really reach the level of quality of data that we needed to continue the research."

The prototype pod they developed can be fitted to NASA's own helicopters. But longer-term, says Brown, the aim is to create a sensor pod design that can be loaned to helicopter operators.

"After their helicopter lands, we will pull the data back and through a curation process, extract segments that are shared with NASA researchers and, more powerfully than that, we then host it online for the more general research community," he adds.

CAMERA TYPES AND TAGS

While the data from the AIRVUE project will help speed the development of detect-and-avoid camera-based systems, the pod itself is "a passive data collection tool,"

"We are working on the cameras to be certifiable, so that they reach the environmental testing standards required for aviation"

1 // The NASA Airborne Instrumentation for Real-world Video of Urban Environments sensor pod is attached to the base of a helicopter at the Kennedy Space Center, Florida in April before a test flight *(Photo: NASA/Isaac Watson)*

says Brown. As such it only has limited computer visioning capabilities on board, sufficient to detect problems in the data capturing such as "a foggy lens or an intermittent data signal."

All the visual data captured by the pod is tagged using high precision GPS / INS (Inertial Navigation Systems) trajectory, meaning that it can be cross-referenced with geospatial data for a given area, allowing drone developers to compare the accuracy of their navigation systems with the real-world geography.

For the cameras themselves, Brown and his team experimented with infrared cameras but found that there was little demand for them among researchers. They have opted instead for standard RGB-based cameras but with several specific requirements particular to the use case.

Brown says, "We need cameras that we can electronically control because we do not have a person there to adjust the focus. We need control software for the cameras. That drives us to cameras that are mainly designed for automotive, aerospace or other industrial uses."

Another requirement for the cameras is the capability to insert a timestamp into the footage. According to Brown, many consumer cameras such as GoPros are ruled out because they can't be integrated with time code standards like IRIG-G. So far Brown and his team have

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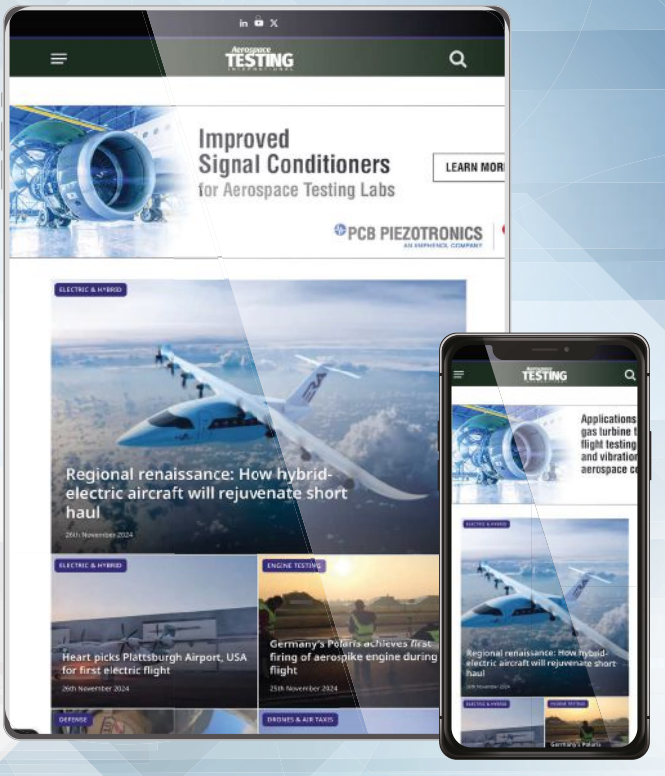
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2 // Reliable Robotics uncrewed flight test of its Cessna Caravan took place during 2023

tried out several different industrial cameras on the prototype for the pod.

They have found that most of them are sufficiently ruggedized to withstand the high vibration environment of helicopter flight, although NASA designers have built a custom mount to protect the lens. The research team are also able to test the durability of the cameras before installing on the helicopter through in-house vibration testing.

HIGH RESOLUTION NEEDS

While Brown and his team continue their search for the ideal off-the-shelf camera, Switzerland-based Daedalean have taken matters into their own hands. Frustrated by the lack of a suitable camera on the market, the company, which is developing autonomous piloting software systems for civil aircraft, decided to make its own.

According to Daedalean's vice president of engineering Sylvain Alarie, the camera it has developed is similar in functionality to conventional cameras but with a much higher resolution.

Most aerospace cameras are typically used for video, which means that the image quality, is not of sufficient quality for computer vision systems, which need to be able to find patterns in pixel-level details and color aberrations too small for the human eye.

"We need cameras that we can electronically control because we do not have a person there to adjust the focus"

3 // Robert Rose, CEO, Reliable Robotics

4 // Inside the pilotless cockpit of Reliable Robotics' test aircraft
(Photos: Reliable Robotics)

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"Usually, off-the-shelf cameras provide good resolution and sharpness in the center of the image, but it's important for our system to have good quality over the complete field of view," says Alarie. "Our camera provides sharpness all over the image."

While there are cameras made specifically for computer vision applications with enough resolution and contrast, they are usually unable to withstand the extreme temperatures and vibrations of flight. "We are working on the cameras to be certifiable so that they reach the environmental testing standards required for aviation," says Alarie.

Daedalean's camera was developed with camera-maker Kaya Instruments, the lens-maker Thorlabs and optical solutions company Dontech, who helped them create the camera's glass cover. The integrated solution consists of the camera, a data processing unit for capturing and processing high-resolution images. It features multiple elements to ensure data quality and security, including leak detection sensors and other components that ensure its performance.

Daedalean's computer vision system uses neural networks to process the camera footage in real time. A visual awareness suite based on it has been designed as a pilot aid able ot detect non-cooperative traffic, ground obstacles like masts and wires, or provide positioning information in the absence of GPS. According to Alarie, possible use cases include search and rescue, emergency medical services, law enforcement and offshore cargo operations.

While the system conducts tasks such as traffic, ground obstacle detection, and navigation in real time based on what it sees, it also has an internal database that stores data on what it has already seen – maps of the regions over which it had flown.

"The database is regularly updated during offline processing based on imagery recorded in-flight. That way – much like humans who

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remember areas they have seen previously – the system continuously extends and amends its knowledge of the environment," says Philipp Krüsi, Daedalean's director of engineering.

"You are updating your mental database with what you are seeing. That is the same thing as what we are doing."

ALTERNATIVE VISION

Both NASA's AIRVUE project and Daedalean's computer vision system rely on the assumption that the future of detect-and-avoid will be camera-based. However, not all companies in the field agree with this assessment.

California-based Reliable Robotics, for example, is developing a detect-and-avoid navigation tool that relies on radar. The choice of a radar-based system was made after Reliable spent time studying the regulatory landscape around autonomous flight, says the company's CEO, Robert Rose.

"If you want your technology or your system to be certified for civilian use, you need to follow standards that the FAA has accepted," says Rose.

"To date, the FAA has only accepted one standard for sensors that can do detect-and-avoid, and that's based on radar."

This standard is the Radio Technical Commission for Aeronautics' (RTCA) standard for technical and testing requirements, RTCA DO-366. In 2017, the FAA published a technical standards order that referenced the RTCA standard, which among other requirements, specifies the total boundaries which must be covered by the radar, the object detection distance, the accuracy, and the number of moving objects that can be tracked simultaneously.

"To date, the FAA has only accepted one standard for sensors that can do detect-and-avoid, and that's based on radar"

4 // Daedalean's visual awareness system has been installed for testing in an Eclipse 550 twinjet in October 2024. Engineers are assessing the system's capabilities for detect-and-avoid traffic deconfliction

5 // The camera pod system installed in a downwards facing position on the wing of Daedalean's Cessna test aircraft

According to Rose, the absence of any other standard means that "if you want to fly an automated aircraft and have a detect-and-avoid system this decade, then it needs to be a radar." As well as being, "the only near-term viable option" for bringing detect-and-avoid to market, radar also has advantages over camera-based computer visioning.

"For localization, we looked at camera systems in the early days of the company, but they have a number of drawbacks," says Rose. "They don't work in certain meteorological conditions, they don't work when you fly through bugs – you get bug splatters in the lens. There are also issues with lighting, when flying directly into the sun.

"And so, we spent more time looking at other ways of localizing the aircraft position, and we figured out that aircraft already have many of the sensors that you would need to get a highly precise position estimate of the aircraft.

"We figured out that there are algorithms you can use that combine your GPS, that combine your VOR (very high frequency omni-directional range), your DME (distance measuring equipment), instrument landing systems, your AHRS (attitude and heading reference system) and your magnetometer. You can fuse all this data in software and come up with a very high precision estimate for where the aircraft is, and that's good enough for landing." \\

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Flying farmers

1

1 // Pyka and Embraer have been working to commercialize autonomous drones for agricultural spraying in Brazil since 2021 (main) while companies such as Rotor are converting existing helicopters with autonomous technology for the US market (inset)

Testing and development of unmanned autonomous drones is being driven by the agricultural sector's quest for cheaper, more effective crop sprayers

While some would prefer to inhabit a world free from agricultural chemicals, it may not be a world where farmers could feed a potential population of 12 billion by 2100. Chemical treatments including pesticides, herbicides, fungicides, and fertilizers must be applied at scale to support yields sufficient to slake humanity's voracious appetite.

Crop-dusting or aerial application, whereby contractors spray vast tracts of land with purpose-built aircraft, is a market worth US$6 billion worldwide – US$3 billion in the USA alone. The European Union outlawed most crop-dusting in 2009, meaning European farmers must rely on self-propelled or tractor-drawn ground-based sprayers.

Crop-dusting costs more than running a sprayer, but rapidly covers ground. "Tractors cause crop damage," says Nathan White, head of flight operations at autonomous UAV developer Pyka. "They can't run in wet or boggy conditions, or through higher crop canopies."

Aircraft cause zero soil compaction and are untroubled by ground conditions, but present other limitations. "Because they have smaller tanks, crop dusters have limited application rates," says agricultural machinery manufacturer New Holland's crop application specialist, Alex Caldwell. "Ground rigs are more precise. Farmers can control exactly when the chemical is applied without being subject to a crop duster's schedule."

SAVING LIVES

For crop dusters, meeting demand depends on pilot availability. "Pilots flying 20ft above ground at 100mph and pulling up sharply to avoid trees or poles are killed more often than police officers," says co-founder and CEO of engineering firm Edison Aerospace, Gene Avakyan. "It's like flying a combat mission."

Saving lives is motivating companies like Pyka and Edison Aerospace to develop UAVs large enough to replace piloted crop-dusting aircraft. Pyka's 38ft (11.5m) -wingspan Pelican Spray is an electric UAV with 620 lbs (280kg) chemical capacity. Purpose-built for agriculture, it travels at 70 to 80mph (112 to 128km/h), spraying 160 to 210 acres/hour in 59ft (18m) wide swathes. Already

"Spraying is dangerous and requires repetitive precision, something robots excel at"

2// The Pelican Spray is purpose built for agricultural applications

3// Early flight testing of the Pelican Spray has resulted in airframe adjustments

4// Rotor's Sprayhawk has a spray rate of 240 acres per hour

operational in Brazil, Costa Rica and Honduras, in 2023 it became the largest UAV to obtain FAA authorization for commercial operations.

Pyka analyzed different aircraft applications to find those most suited to electrified autonomy. "Crop-spraying was the resounding winner," says White. "Range, the one downside of electric aircraft, just isn't an issue, since crop-dusters can easily swap batteries when landing to refill chemical tanks. Spraying is also dangerous and requires repetitive precision, something robots excel at."

APPLICATION-SPECIFIC DESIGN

Pelican Spray's distributed architecture ranges four electric motors across its wings, providing 100kW of total power to composite, fixed-pitch propellers. If a motor experiences an outage, the plane can safely continue its mission. Distributed propulsion also delivers a cleaner airflow.

3

4

"A traditional aircraft's single nose propeller creates a downwash which disturbs spray from the boom, but our propwash stays above the boom," White explains. The Pelican needs only a 600ft runway, far shorter than gas turbine aircraft thanks to its superior peak power-to-weight. It doesn't use visible light to fly, enabling nocturnal operation.

"In Costa Rica, flying at night is too dangerous and the days too hot for spraying. Pilots are limited to narrow, windows during dawn and dusk and have to tolerate less-than-ideal wind conditions to avoid chemical drift. Pelican Spray allows them to apply at night, when winds are low and many plants absorb chemicals more efficiently."

Six processors on two separate computers process millions of sensor inputs per second. Redundant inertial measurement units and air data booms replicate a pilot's instruments and orient the aircraft. Forward-facing lidars for obstacle detection and downward-facing 3D lidars for field-scanning work are separate systems each with self-contained logic.

"Each mission begins with a scan-pattern flight at 100m," White says. Downward-facing lidar captures and condenses all the obstacles and topography into a map. "The plane then computes a path based on a required spraying polygon and takes off and lands autonomously."

A previous Pyka aircraft, the Egret, was certified for commercial operation in New Zealand. Swapping from tail wheel to nose wheel landing gear between the Egret and Pelican eliminated directional stability and yaw control issues. "We used an iterative development process light on simulation and reliant on real-world flight-testing," says White.

Structural ground tests subjected wings to the loads they would encounter in aggressive maneuvers or gusty conditions. "We had some prototype wings fail load testing, made corresponding design changes, and now have a solid structure locked in."

Certification efforts entailed prescriptive flight-test campaigns. New Zealand's regulators interrogated the Egret's stall characteristics,

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6

"If a drone produces a 160 acre weed map, the file may take so long to download that new weeds may appear"

5

5 // Pyka is using technology and knowledge from its cargo drone for the Pelican Spray

6 // Alex Caldwell, crop application specialist at New Holland

7 // Pyka flight tests software updates in California, USA

maximum speed and stability conditions across forty flight hours. The FAA began by reviewing the Pelican's concept of operations.

"That determined how rigorously they needed to regulate it," White explains. "Our proposed mission, flying low in sparsely-populated areas, has low air- and ground risk."

After this an exhaustive review of Pyka's flight, maintenance and training manuals, with FAA departments suggesting improvements was done. FAA flight tests focused on emergency procedures outlined in the flight manual. Pyka injected faults by disabling a motor, sensor, or servo, to ensure system logic responded correctly and safe flight could continue. "It's about showing the airplane handles potential failures as described," says White.

FAA approval means the Pelican may be flown by operators with an exemption certificate, but not yet by individual farmers and Pyka delivered its first US plane to Heinen Brothers, a Kansas crop-spraying service provider in February 2024, after a three-year certification process, although certification in other regions should be faster. Certification in Costa Rica and Honduras resembled the FAA process, whereas to promote a technology perceived as low-risk, Brazil allows agricultural drones to operate without an airworthiness process.

Pyka conducts ongoing flight-tests in central California to validate software updates. "We have a certificate of authorization and run operations five days a week, all year round," says White.

MARKET GROWTH

According to Edison Aerospace, its Heavy 1 electric UAV will be cheaper to build than the Pelican with off-shelf components and offer a more

7

PRAY AND SPRAY NO MORE THANKS TO ACADEMIC RESEARCHERS

Chair of agricultural and biosystems engineering at North Dakota State University, professor Leon Schumacher is assisting Edison Aerospace in testing the spray performance and operation of its proposed Heavy 1 autonomous aircraft.

"A field sprayer may have 15 or 20in nozzle spacings, but an aircraft may need nozzles 6 to 9" apart to reduce the impact of winds on the spray pattern. Spray width is generally three quarters of the wingspan, from which we can determine the required pump size. We need to keep product agitated in the tank, so it remains suspended to produce a uniform application."

Pyka's Pelican Spray UAV crop-duster combines variable-speed rotary atomizers with a high-speed centrifugal electric pump in a spray system allowing users to adjust the flow rate and droplet size for optimal application efficiency. Iterative flight tests may perfect the spray patterns delivered by Edison's system. "We can put water-sensitive paper at different locations in the field to test uniformity of application across the boom," says Schumacher.

Schumacher argues that Edison should aspire to incorporate sense-and-act technology capable of detecting and spraying individual plants to provide an environmentally friendly and range-extending solution. "It wouldn't be impossible in a two-drone approach, with a smaller drone first spotting the weeds to generate a prescription for the aircraft applying the product."

Schumacher observes that the FAA currently prohibits the use of spraying drones above 50lbs in total weight without a special license. Depending on application rates, this may only provide the capacity to spray a single acre. "We should think more about spot-spraying, combining additional drones with AI to pinpoint trouble-spots and apply product only where needed," he says.

"We used generic aircraft because our goal was to test navigation and flight control systems not the propulsion"

8

competitive 200 gallon payload. "Pyka created a Rolls Royce, but we want to make a Ford," says Edison CEO, Gene Avakyan. "Something simple, robust and widely affordable — a tractor that flies."

The 40ft (12m)-wingspan Heavy 1 will also leverage distributed electric propulsion. Its architecture features four propellers across each wing driven by eight separate motors. "That creates a blown-wing effect, improving the airfoil's efficiency and allowing it to fly more slowly without stalling," says Avakyan. "It eliminates the P-factor, whereby increasing RPM creates a spiraling airflow which causes single-propellor aircraft to yaw to one side."

Avakyan's airframe design is patent-pending and he is seeking funding for a half-scale prototype, having developed a semi-autonomous flight control system using open-source software. "It's a human-in-the-loop system which automates takeoff and landing," he explains. "A pilot controls it remotely, but if they let go of the sticks, it automatically levels itself to fly steady."

Avakyan has so far flight-tested in Florida with 2ft (0.6m) models. "We used generic aircraft because our goal was to test navigation and flight control systems not the propulsion. I have no doubt about that, because NASA has tested similar propulsion technologies and all the numbers work."

Once built, Avakyan plans initial flights under an experimental license with a pilot flying the Heavy 1 from a trailer-based ground control station. A person will remain outside to maintain visual line-of-sight.

Crop-dusting operators represent Edison's target customers for an aircraft intended to replace their conventional planes and be flown by commercially-licensed pilots from a cockpit-like control station. By contrast, the Pelican can be operated via a laptop after some basic training and may be marketed to operators or directly to large farms.

8// Automation of the low altitude flying needed for spraying will improve safety

9// The Edison Heavy uses the blown-wing effect to fly slowly and improve spraying efficiency

9

The backdrop to Pelican Spray's advancing deployment is an emergent US market in smaller UAVs with spraying capabilities. Developed in partnership with Chinese manufacturer XAG, a New Holland drone spraying solution showcased alongside the Guardian will be available to Brazilian customers in 30 litre and 70 litre models later this year.

"The New Holland Spraying Drone completes a 30 litre to 4,500 litre range of spraying solutions aimed at every type of producer," says Eduardo Kerbualy, New Holland's vice president for Latin America. It is expected to excel on smaller plots, uneven topographies and fields inaccessible to tractors following rainfall.

John Deere and German multirotor drone company Volocopter started working together on an agricultural drone in 2019, but Volocopter paused its pursuit of agricultural applications precluded by European regulations. While skeptical about the precision of small UAV sprayers, James acknowledges the potential for UAVs in scouting applications like providing weed maps to inform ground-based spraying.

"The problem then is data-processing time," says Caldwell. "If a drone produces a weed map for a 160-acre section, the file may take so long to download that new weeds have appeared in the meantime." \\

WORLD'S LARGEST AGRI-SPRAY DRONE UNVEILED BY US COMPANY

By Chris McCullough

Equipped with 33ft (10m) booms and a 110 gallon (500 litre) capacity tank the new Sprayhawk drone is being classed as the biggest agri spray drone on the market.

Designed and developed by Rotor Technologies, based in New Hampshire, USA, this new UAV has just been released onto the market with a hefty introductory price tag of US$900,000.

The machine is based on a full-sized Robinson R44 helicopter and is fully controlled by a two man operator crew on the ground.

With a spray rate of 240 acres per hour, the Sprayhawk can take off and land vertically. It features autonomous spray path and terrain following algorithms, as well as camera and LIDAR sensors for detecting wires and avoiding obstacles.

Powering the Sprayhawk is a Lycoming six-cylinder aviation engine that can propel a spray rate to over 80mph (112 km/h). It has a flight time of 50 minutes between refuelling.

Impressively, the Sprayhawk matches the spray speed and capacity of manned aircraft, while offering significantly lower operating costs and improved safety.

Rotor's CEO Hector Xu said, "The Sprayhawk represents a leap forward in agricultural aviation. We've combined the capabilities of a full-scale helicopter with the cost-effectiveness and safety of a drone. There's nothing else on the market that's as productive, reliable, and future-proof as this."

Rotor was founded by a team of MIT aerospace engineers and aerospace industry veterans. The company manufactures the most capable commercial UAVs in the world, designed for challenging and dangerous missions like crop dusting, aerial firefighting, and utility work.

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SAMPLE IV PROJECT MEASURES ENGINE EMISSIONS

A European project to measure the particulate matter emitted by non-regulated aero engines is informing the creation of environmental emissions regulations

Air travel is one of the fastest and most efficient means of transport and is seen as crucial for the global economy. Nevertheless, it has drawbacks related to emissions which impact the environment and human health. Particle emissions as well as gaseous contribute to the hazard. Especially small particles less than 0.1µm in diameter emitted by aircraft can reach the alveoli in lungs and cause severe health problems. The EU is therefore implementing a series of regulations that restrict aviation emissions.

The SAMPLE IV Project is funded by the European Aviation Safety Agency (EASA) through the Horizon 2020 Research and Innovation Program Societal Challenge 4 "Smart Green and Integrated Transport". The project aims to assess the emissions of non-regulated engines –with a thrust of less than 26.7kN – to propose improvements in engine emission measurement regulations, as well as more robust practices.

SAMPLE IV project participants include: Instituto Nacional de Técnica Aeroespacial (INTA) – the project coordinator, Cardiff University, the University of Manchester, Universidad Politécnica de Madrid, Zurich University and Rolls-Royce.

The presence of non-regulated engines in airports can reach up to 30%, as is the case for example at Riga Airport in Latvia. Their emissions and the measurement techniques used with these engines must be assessed for regulatory purposes. The main activities within the scope of SAMPLE IV are: to evaluate the presence of non-regulated engines in different airports; to propose and assess new measurement techniques for particulate matter, and to conduct gaseous and particulate matter measurement campaigns for this type of non-regulated engines.

Three measurement campaigns are being carried out. The first was carried out in September 2023 at Hawarden Airport, UK and was led by the University of Manchester and Cardiff University. In this campaign, emissions from a turbofan Honeywell ALF 502/LF 507 engine were measured.

1

1 // PW127G engine aircraft mounted on a C295 for the INTA measurement campaign. Engine exit exhaust appreciation with probe and sampling lines

In October 2024 another measurement campaign was carried out by INTA in its facilities. A PW127G engine mounted on a C295 turboprop aircraft was used. During this test campaign, the emissions emitted by the engine were measured by different instruments while varying engine power conditions.

A probe was situated a few centimeters from the engine exhaust. This probe collected the emissions and transported them to the measurement instruments through the sampling lines. These instruments were located at a distance of 25m from the probe inside a cabin and in the probe structure itself, in order to minimize losses. The different emissions were monitored to assess how they change as the power conditions of the engine were varied.

Finally, the last measurement campaign will occur in Cardiff by the end of 2024. The emissions from a turboprop aircraft mounted with a TP331 engine will be evaluated.

The next step after the three campaigns is to analyze the data obtained and propose improvements to the emission measurement regulations for aircraft engines, helping to achieve more robust practices and seeking to achieve a more sustainable world in terms of aviation. \\

2

2 // Instruments placed inside of the cabin and in the probe structure of the INTA measurement campaign

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FLIGHT RECORDERS THAT RISE TO THE CHALLENGE

Flight recorders are already meeting the optical data needs of today's military aircraft

The amount of sensor data collected by military aircraft has grown tremendously in recent years – especially in the optical realm. While this dramatically improves situational awareness, it also greatly taxes the flight recorders in a way never seen before.

The industry is racing to find answers to a critical challenge – how to source ruggedized, flight-worthy recorders that can transmit and store enormous amounts of data at extreme rates. These new platforms and systems present unprecedented data generation and recording requirements, creating demand that most current offerings cannot meet.

It's a problem Calculex has been addressing for over 30 years, and the company is rising to the challenge with solutions that have already achieved the DoD's Initial Operating Capability (IOC). The company is also ramping up to provide even greater capabilities as optical sensors grow more prevalent and will undoubtedly be standard equipment on all new military aircraft going forward.

Many newer flight recorders can provide a previously unheard-of data rate of 10GB ethernet on one band. Now, the industry is asking for a step change in transmission speed, with multiple 10Gbps ethernet channels alongside ones with 25Gbps capabilities.

To meet these requirements, Calculex developed the Raptor – a high-speed fiber optic data recorder supporting 2Gbps, 10Gbps, and 25Gbps per channel. With 24 available channels, the Raptor represents a new standard that enables a distinct, yet synchronized, channel for each sensor — fully programmable by the user.

To store vast amounts of data, this unit features an ultra-high density Removable Memory Module (RMM), that offers 132TB capacity, expandable up to 570TB. To meet the high-stress needs of the aircraft environment, the Raptor is completely ruggedized and fits into a remarkably small case weighing only 35 lbs (16kg). It also has robust thermal-management capabilities to keep the unit cool, with even greater advances planned for future models.

1

In today's threat environment, aircraft equipped with the capacity to handle optical, radar, IR and other inputs will rely on a fast optical ethernet backbone — a vast leap from yesterday's 1553 standard. The Raptor's ability to record up to four hours at these advanced speeds is a true first in the industry, as is the ability to stream data continuously without any buffering or the need to stop and save data.

As Calculex looks to further enhance the capabilities of these recorders, the company is working on RMMs that can manage up to 730TB of data without expansion. In an ISR scenario, for example, this would allow for real-time monitoring of multiple sensors while recording all the radar transmissions trained on an aircraft. This defensive capability empowers a pilot to easily map out anything on the ground targeting the aircraft.

Impressive as that is, Calculex is already fielding requests for even higher speeds. This will be addressed with four, 25Gbps ethernet channels that can be combined into 100Gbps. Critical here is the ability to time-align all these inputs so that, regardless of the media, up to 24 channels can be merged into one recording. These are precisely overlaid within sub-microsecond accuracy and continuously checked with one another to reveal any anomalies.

Calculex set the standards for flight recorders since the early 1990s. With the ever-increasing need for speed and storage housed in small, ruggedized units, the company is at the forefront once again in creating advanced solutions for military aircraft today — and tomorrow. \\

2

1 // Modern military aircraft feature greater situational awareness, which produces more data to record

2 // Flight recorders such as Calculex's Raptor provide increased speed and capacity to deal with large amounts of data

3 // The Raptor features 24 high-speed fiber optic channels

3

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REDUCING SIMULATION SETUP TIME

Off-the-shelf models for aircraft battery and fuel cell simulation

Cutting greenhouse gas emissions is one of the main priorities of aerospace companies. Electronics and smart software enable the transformation to more electric aircraft, electric or hydrogen propulsion, and highly automated or even autonomous air transportation. Electric drives and advanced power electronics play a key role in novel aircraft design, supporting electronic architectures powered by batteries or fuel cells. This requires an increasing amount of control units with smart control algorithms to manage more and more tasks.

A battery management system (BMS) monitors and controls the state of charge and provides battery protection with functions such as thermal management. In this context, virtual system integration tests are crucial to detect defects at an early development stage to reduce costs. However, the setup of a virtual environment for simulation is a demanding challenge, particularly when it comes to design and modeling tasks. Companies are looking for ways to speed up these tasks to meet their deadlines.

System simulation models that set up a realistic test environment and can directly be used to design and test controller algorithms cover this demand out of the box. The ASM tool suite from dSPACE provides exactly this. Ready-to-use Simulink models accelerate system design and integration testing with maximum modularity and flexibility. It performs on both virtual and real-time platforms so that the preparation of the test setup can be shifted to the early project phases and tests can be frontloaded.

The implementation of each model is traceable down to the Simulink basic block level because ASM provides open, modular and scalable simulation models. This makes it suitable to extend or replace components with customer-specific parts and adapt to individual projects. The standardized interfaces of the ASM tool suite make it easy to extend and combine with different ASM products with third-party models to create entire digital twins.

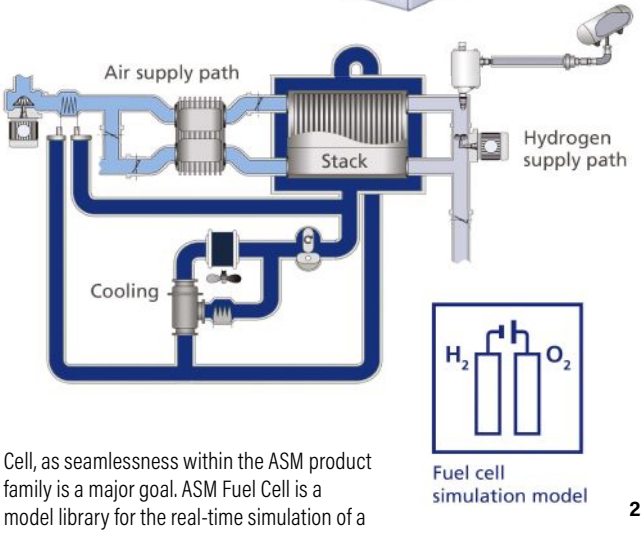
For the challenges specific to aerospace, ASM Battery, ASM Fuel Cell, and ASM Electric Components assist engineers in the early phases of controller development and in the validation of control units. With the models from ASM Battery, the voltage behavior of a battery from low to high voltages is simulated physically correct in real-time, such that it decisively drives the development of batteries and BMS.

ASM Battery can be combined with further ASM libraries, such as ASM Fuel Cell, as seamlessness within the ASM product family is a major goal. ASM Fuel Cell is a model library for the real-time simulation of a proton exchange membrane fuel cell system. ASM Battery and ASM Fuel Cell can be complemented with ASM Electric Components, a library of models to simulate the remaining electrical system to reduce the time-consuming design and modeling tasks even further. Each ASM library provides its own software controller to simulate missing controllers or to operate and validate the plant without the absolute need to integrate the final control unit in the loop.

The models are fully supported by dSPACE tools for parameterization (ModelDesk) and instrumentation (ControlDesk). Furthermore, in case of advanced requirements in electric drive or power electronics simulation, XSG Electric Components and the Electrical Power Systems Simulation Package will enhance your simulation environment with high-precision models based on FPGA technology and ready for sampling rates in the range of nanoseconds.

In summary, the ASM tool suite together with FPGA-based models from dSPACE effectively supports system development and testing by significantly reducing the simulation setup time. This allows development resources to be focused on value-adding key competencies and know-how, hence increasing the overall efficiency of the development process. \\

1



2

1 // Out-of-the-box simulation models used in ControlDesk

2 // A typical fuel cell system consists of the fuel cell stack, an air supply path, a hydrogen supply path, and a cooling circuit

dSPACE - ASM Fuel Cell

dSPACE - ASM Battery

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SHAKER TESTING ENSURES RELIABILITY AND SAFETY

Vibration testing continues to form a vital part of aerospace development and testing

Shaker testing is a critical component of aerospace development. It simulates the dynamic forces and vibrations an aircraft or spacecraft will experience during flight. It is a rigorous process designed to identify potential weaknesses and failures and ensure the structural integrity of these complex systems.

Shaker testing involves subjecting a test article, such as a component, subsystem, or an entire aircraft to controlled vibrations. A shaker system generates these vibrations using different waveforms and frequencies. The test article is securely mounted to the platform, and sensors are strategically placed to measure the structure's response to the induced vibrations.

There are different modes of shaker testing. For instance in sine vibration testing a single frequency is applied to the test article. This is useful for simulating specific frequencies that may occur during flight, such as engine vibrations or turbulence. Random vibration testing involves applying a wide range of frequencies simultaneously, simulating the complex and unpredictable vibrations encountered in flight. This is particularly important for creating the effects of atmospheric turbulence and acoustic noise.

To create the sudden, impulsive loads that can occur during events like landing, take-off or the deployment of pyrotechnics, the test article is subjected to a high-intensity shock pulse.

There are, of course, key applications in shaker testing in the aerospace domain. Component qualification is essential for qualifying individual components, such as avionics, hydraulic systems and structural elements to make certain they will withstand the dynamic loads experienced during flight.

Similarly, it is necessary to test subsystems such as landing gear and flight control systems. They will also be subjected to intensive shaker testing to demonstrate structural integrity and safety.

Before the aircraft is certified for flight, it must undergo extensive shaker testing to demonstrate its safety and integrity.

And finally, for spacecraft testing, it must be shown that components, subsystems, and assemblies can withstand rigorous shaker testing to simulate the harsh vibrations and acoustics associated with launch and space flight.

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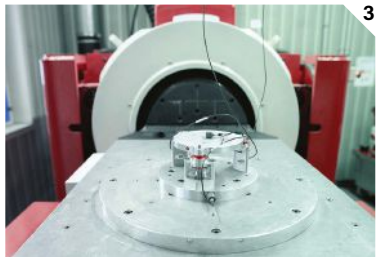

3

There are clear benefits in using shaker systems to prove the reliability of aerospace products. They can provide a platform to detect early failures, identifying potential structural weaknesses or component failures before they occur in flight, preventing catastrophic events.

Products are also greatly improved in terms of reliability and development costs and time reduction. Addressing design issues with accelerated testing enables you to bring products to market faster.

However, shaker testing is not straightforward. There are many considerations to take into account when selecting the right shaker, selecting the right vibration control strategy and correct mounting of the device under test (DUT). The test fixture design will dictate how accurately the in-service environment of the DUT is simulated. Sensor or accelerometer placement is critical to ensure the specimen is not over-tested or under-tested. In addition, analyzing the vast amount of data created by shaker testing requires sophisticated software and expertise. There are also practical considerations of productivity and test duration, especially for large and complex test articles such as satellites.

Shaker testing is a vital and unavoidable investment in aerospace engineering. By simulating the dynamic forces and vibrations experienced during flight, it helps ensure the structural integrity, reliability, and safety of aircraft and spacecraft. As technology advances, shaker testing will remain an essential component of the aerospace development process. \\

1 // Satellite on shaker table *(Photo: INPE)*

2 // HBK's LDS V8900 shaker

3 // A typical shaker table setup in a laboratory *(Photo: SMAC)*

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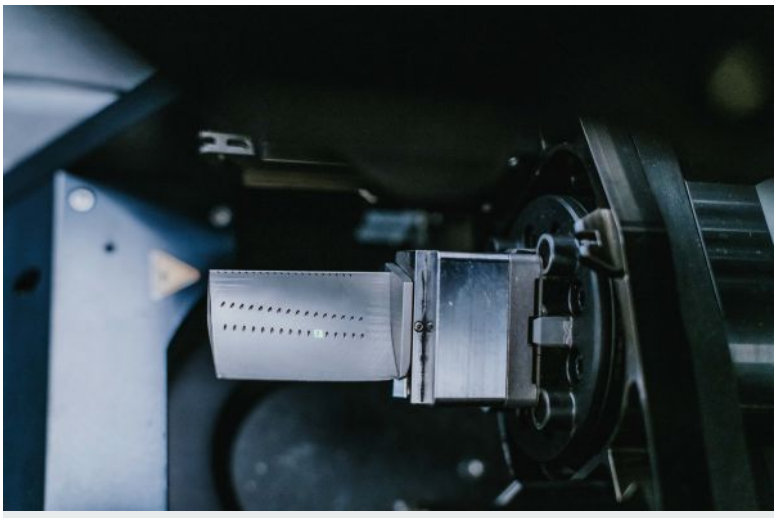

COMPREHENSIVE COOLING HOLE INSPECTION

In the demanding field of turbine blade manufacturing, precision and reliability are non-negotiable. Engineers are constantly on the lookout for solutions that ensure the highest standards of safety and efficiency. The Bruker Alicona Cooling Hole solution is the definitive choice for comprehensive cooling hole measurements, offering unparalleled accuracy and ease of use.

Turbine blades must endure extreme temperatures, necessitating efficient cooling mechanisms to prevent overheating and ensure safe operation. The intricate cooling holes drilled into these blades are critical for maintaining optimal performance. However, accurately measuring these complex geometries has always posed engineers with a significant challenge.

The Bruker Alicona Cooling Hole solution revolutionizes this process. Using advanced focus-variation technology, it provides precise measurements of the geometry, position, and orientation of cooling holes. The non-contact, high-resolution 3D measurement system captures even the smallest details, ensuring that every cooling hole meets stringent specifications.

The Bruker Alicona solution enhances safety by ensuring that cooling holes are measured with the highest accuracy, reducing the risk of blade failure due to overheating. This reliability translates directly into safer turbine operations, giving engineers peace of mind. Efficiency is another critical factor. The Bruker Alicona Cooling Hole solution significantly enhances turbine efficiency by enabling higher operating temperatures.

The Bruker Alicona Cooling Hole Add-on represents a significant leap forward. It offers a robust and reliable method for ensuring the quality and performance of turbine blades. By adopting this technology, engineers can achieve unprecedented levels of precision, ultimately leading to safer and more efficient turbine operations.

This solution represents not just an improvement – it is the definitive choice for comprehensive and accurate cooling hole measurements. \\

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HIGH SPEED DAQ WITH INTEGRATED CHARGE AMPLIFIER

The Elsys DAQ system family has been further developed in collaboration with Kistler. A new device type is now available under the device designation "Transient Recorder Type 2529A" with an integrated Kistler charge amplifier. Each channel is multifunctional and can be configured as a voltage, IEPE or now newly as a charge channel. The charge inputs are characterized by a high bandwidth of more than 500kHz. The input range can be adjusted from ±120 to ±100,000 pC.

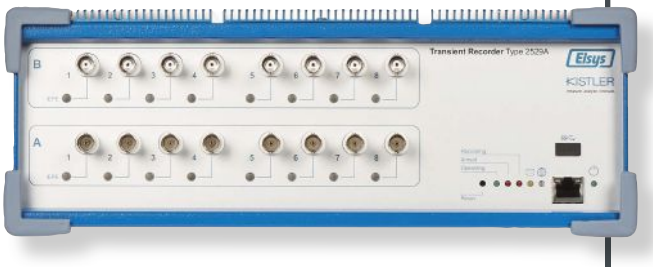
The 2529A is available with sampling rates from 200 kHz to 20 MS/s per channel. The device can be equipped with 8 or 16 input channels where 2 or more of the channels can have the additional charge input option.

A variety of application software programs are available to operate the device. BallAX is optimal for ballistic measurements in R&D settings. KiDynamic software from Kistler caters specifically to EPVAT (AEP-97), CIP, and SAAMI measurements.

For other uses, the versatile TranAX software stands out, especially with its latest version 4.2, which includes advanced data visualization and analysis features. These features include spectrogram and waterfall plot displays, making it a robust tool for frequency domain analysis, often used in acoustic emission and structural health monitoring. The integrated formula editor enhances post-processing capabilities, enabling filtering, searching, and scalar calculations. Additionally, the latest version supports Python code execution, facilitating the automation of measurement and data management tasks. Custom software connections are easily achieved via APIs in various programming languages.

Multiple devices can be linked to form larger systems. Synchronization is achievable through IEEE1588, GNSS, or the proprietary SyncLink.

The continuous evolution of Elsys DAQ devices will see the addition of strain gauge connections for dynamic measurements, anticipated to be introduced in 2025.\\



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A UNIFIED APPROACH TO TACKLING THE STRUGGLES OF 3D MEASUREMENT TEAMS

Today, manufacturing companies operate sophisticated 3D measurement labs equipped with different types of portable and CNC CMMs. Each brand of hardware typically uses its own software. Some companies find themselves using over five different software brands for their 3D measurement needs.

For example, they may use one or two software programs for their digital gauges; two or three for portable metrology systems like scanning arms, structured-light scanners, and laser trackers; and one or two on their CMMs, often provided by the CMM manufacturers themselves.

When relying on multiple software programs, multiple workflows must be mastered, which hinders the performance of 3D measurement teams.

Replacing those software with a universal software platform addresses the struggles of measurement teams and significantly increases 3D metrology efficiency.

Organizations that have implemented a universal 3D metrology software platform report substantial reductions in their measurement costs. Training costs are lowered because team members only need to learn one software. Additionally, software maintenance costs decrease due to fewer updates. Furthermore, the time required for hardware-independent inspection steps is reduced by thousands of person hours annually, as these steps are completed only once per inspection.

Moreover, companies have boosted the performance of their 3D measurement teams. Portable metrology operators can now easily learn how to operate CMMs, and CMM operators can master portable metrology, increasing team versatility and making it easier to manage staff absences or device unavailability.

Operators also gain deeper dimensional inspection knowledge using a single software. And the risk of human error when duplicating projects has been eliminated.

Adopting a universal 3D metrology software platform not only streamlines workflows and reduces costs but also empowers measurement teams with greater versatility, adaptability, and efficiency.\\

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Aerospace Test & Development Show 35
AIM GmbH 55
Amentum 43
Bruker Alicona 13
Calculex 13
Curtiss-Wright Defense Solutions ..... Inside Front Cover
Diversified Technical Systems (DTS) 49
dSpace 19
DÜRR NDT 49
Elsys 21
Evolution Measurement ..... Inside Back Cover
HBK 25
Innovmetric Software 26
INTA 51
Kistler 21
NetAcquire Corporation 5
Photron 37
Pickering Interfaces 51
Raven Defense 8
REL ..... Outside Back Cover
TEST-FUCHS GmbH 55
TESTIA 47
Vibrac 29

BLENDED WING

The X-48 advanced knowledge about blended wing aircraft designs, but failed to kickstart a full-scale development program

There have been several attempts to create a blended wing aircraft during the past hundred years. The first, the Westland Dreadnought in 1924 ended in a tragic crash. The latest, JetZero in the USA, aims to fly a blended wing aircraft the size of a Boeing 757 in 2027. But the aircraft that has advanced the novel concept the most is NASA's X-48.

The beginnings of the X-48 experimental aircraft can be traced back to work done at McDonnell Douglas during the 1990s. Following the merger with Boeing in 1997, a propeller-driven blended wing body (BWB) model with a 5.2m (17ft) wingspan was built and flown.

This led to engineers at Boeing and NASA designing a high capacity, long range BWB transport aircraft powered by three turbojet engines. The aircraft was designated X-48A in 2001. The plan was to build a 14% scale model of the BWB transport aircraft with a 10.7m (35ft) wingspan and fly it in 2004.

Unfortunately, NASA canceled the construction of this scaled model in 2002. But development of X-48 continued. Boeing contracted UK company Cranfield Aerospace to design and build a smaller 8.5% model with a 6.4m (21ft) wingspan.

Cranfield Aerospace produced two remotely controlled X-48Bs. The first, X-48A completed 250 hours of wind tunnel tests at NASA's Langley Research Center in May 2006. It then made its maiden flight of 31 minutes on July 20, 2007 at NASA's Dryden facility, reaching an altitude of 7,500ft. The initial phase of flight testing was completed in March 2010.

The second X-48 was modified to become the X-48C and was used in a second phase of flight testing. NASA engineers made several changes to the design to reduce the amount of noise X-48 produced and improve low speed stability and control. The X-48C was powered by two Advanced Micro Turbo turbojet engines instead of three engines, the winglets were moved to either side of the engines, and the fuselage extended 2ft at the rear. X-48C flight testing started in August 2012 and concluded in April 2013.

In total, the X-48 flew 122 times at NASA Dryden between 2007 and 2013, 92 times as the B-model and 30 as the C-model. Following the completion of X-48C flight testing in 2013, Boeing and NASA announced plans to develop a larger BWB demonstrator capable of transonic flight. These plans failed to materialize, despite the positive results and the large estimated achievable fuel savings a BWB would provide.

Instead, a X-48 successor is now being developed by JetZero. The company's founders include Mark Page, and senior managers include Bob Liebeck and Blaine Rawdon. They are credited with inventing the X-48 at McDonnell Douglas and were key members of the NASA program.

X-48B/C VITAL STATISTICS

20FT 5IN
Wingspan

500LBS
Weight

137MPH
Speed

10,000FT
Ceiling

156 / 178LBS
of thrust

3x JetCat P200 turbojet (B) / 2x SPT15 JetCat Ducted Fan (C)

// X-48B parked on Rogers Dry Lake adjacent to NASA Dryden in 2006 (right) and during a test flight (above)

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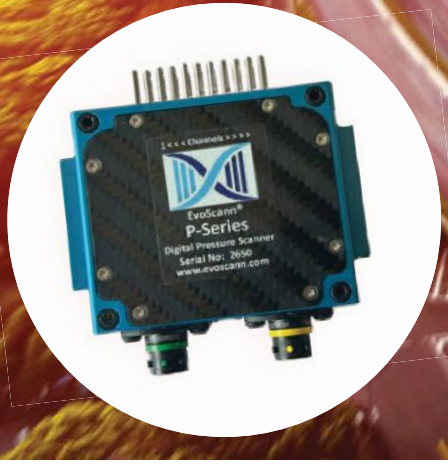

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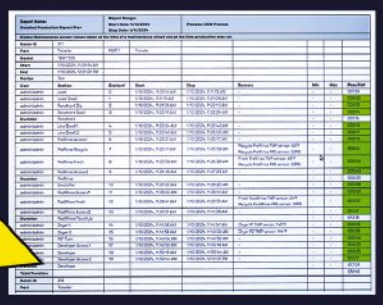

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